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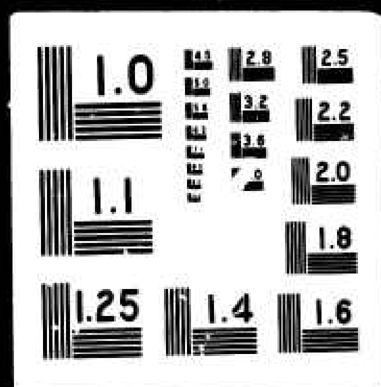

SEISMIC DATA LABORATORY

QUARTERLY TECHNICAL SUMMARY REPORT

OCTOBER - DECEMBER 1967

24 JANUARY 1968

AFTAC Project No.:	VELA T/6702
Project Title:	Seismic Data Laboratory
ARPA Order No.:	624
ARPA Program Code No.:	5810
Name of Contractor:	TELEDYNE, INC.
Contract No.:	F 33657-67-C-1313
Date of Contract:	2 March 1967
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Contract Expiration Date:	1 March 1968
Project Manager:	William C. Dean (703) 836-7644

P.O. Box 334, Alexandria, Virginia

AVAILABILITY

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The work reported herein was supported by the Advanced Research Projects Agency, Nuclear Test Detection Office, under Project VELA-UNIFORM and accomplished under the technical direction of the Air Force Technical Applications Center under Contract F 33657-67-C-1313.

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I. INTRODUCTION

This quarterly technical summary report covers the work performed during the period October through December 1967. Work previously completed or currently in progress is mentioned only as it relates to analyses completed during this reporting period.

Analyses completed for which results have been reported are discussed in Section II under descriptive headings, Section III contains a discussion of the support and service tasks performed for in-house projects and for other VELA-Uniform participants. Appendix A is a listing of those organizations receiving SDL data services during this period.

II. WORK COMPLETED

A. Power Spectra and Noise-reducing Qualities of LASA Beams

Short-period (SPZ) and long-period (LPZ) LASA data are discussed concurrently in this report. The results for SPZ data supplement SDL Report No. 198, "A Beamforming Study Using Outputs from the Extended E3 Subarray at the Montana LASA". The objective here is to present plots of noise power spectral estimates of outputs from E3 beams. We are interested first in the general similarities of the spectra, and second in the effect of inter-sensor spacing on noise power reduction at the output of 7-element beams.

The SPZ data relate long-period noise reduction to inter-sensor spacing at the Montana LASA. Our basic procedure was to prefilter and beamsteer a fixed number of traces while varying the spatial separation of elements contributing to the beams. We are interested specifically in the average rms noise reduction as well as the decrease in the level of noise which is computed from the zero-lag correlations.

Procedure

Our short-period data are noise seismograms recorded by vertical-component sensors in the extended E3 subarray at the Montana LASA during the period 8-17 March 1967. The data,

which were recorded between the hours 7:00 PM and 4:30 AM (Montana local time), were detrended and demagnified before infinite-velocity beams were formed. Magnification levels for 11 January 1967 were used to convert trace displacement, in counts, to equivalent earth motion, in $m\mu$, at 1 cps. Power spectra are based on prefiltered (0.4-3.0 cps) outputs from the beams and individual sensors using 60 seconds of data (1200 digital points) and 120 lags.

In the case of 7-element beams, short-period noise power reduction at each frequency was computed in the following manner:

$$db = 10 \log \left[\frac{\text{power on beam output}}{\text{average power input}}\right]$$

The long-period noise seismograms used in this study were recorded by vertical-component sensors in the interval 18 November 1966-20 January 1967. During the period LPZ seismometers at the Montana LASA were operating on response "A", which peaks at a period of 25 seconds. Prior to forming infinite-velocity beams, we detrended, demagnified, and prefiltered the time series. Magnification levels for 6 March 1967 were used to correct the traces to equivalent earth motion at the peak response. A 4-pole Butterworth filter was used to limit the traces to the band 15-50 seconds.

Two experimental methods were used to compute long-period noise reduction as follows:

$$db = 20 \log \left[\frac{\text{rms on beam output}}{\text{average rms input}}\right]$$

and

$$db = -10 \left[\log N - \log \{1 + (N-1)\tilde{\rho}\}\right]$$

where $\tilde{\rho} = \overline{M}/\overline{N}^2$ is the ratio of the average zero-lag cross-correlation to the average zero-lag autocorrelation, as described by Hartenberger and Shumway (1967). Each long-period beam was formed several times, using a different noise sample each time to obtain the average noise reduction values plotted on Figure 1.

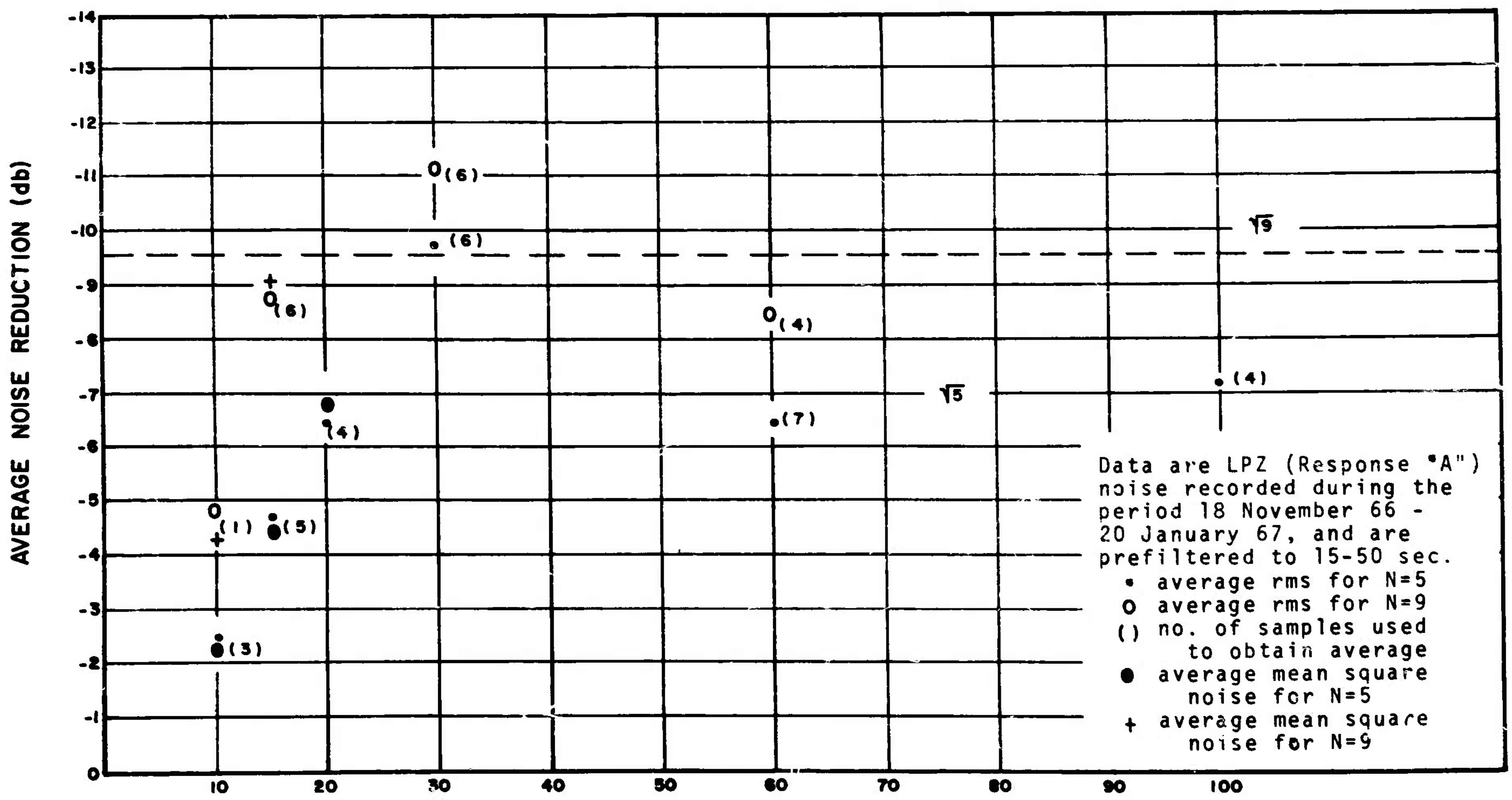

Figure 1 - Average Long Period Noise Reduction At The Montana LASA Using Two Experimental Methods.

Results

Short-period Noise. Figure 2 shows plots of noise power as a function of frequency for data recorded on March 8. The spectra for other noise samples are similar. Decibel scales and arrows marking the 1 cps power points have been added to facilitate interpretation. The average of the 25 individual spectra is also shown on the figure. Noise power peaks at 0.5 and 2 cps predominate on most of the spectra; an exceptionally high value at 2.3 cps is shown in Figure 2.

Referring to Figure 2, it is interesting to note that noise power at 1 cps at the output of the 19-element beam is about the same as that on the 25-element beam output. A similar relationship was observed between the 25-element and 18-element beams. Equivalent noise power levels at 1 cps on outputs of 18, 19, and 25-element beams are attributed either to a higher average input to the 25-element beam or to the possibility that the noise is more correlated between the additional channels of the larger beam.

Figure 3 shows plots of noise power versus frequency for outputs from 7-element E3 beams; recording date and time interval correspond to those in Figure 2. We have included these data to illustrate the effects of inter-sensor spacing, Δ, which changes from 3 kilometers on the left side of the figures to 6, 8, and finally 9.5 kilometers on the right. This effect is further illustrated in the following discussion.

Noise power reduction (in db) at the output of 7-element E3 beams is shown as a function of inter-sensor spacing in Figure 4. For the frequencies shown, these data correspond to those shown in Figure 3, but are more meaningful in the sense that the noise reduction is relative to the average power input to the beams at each frequency. As shown in Figure 4, noise power at 1 cps is reduced approximately by a factor of N at $\Delta \geq$ 6 km.

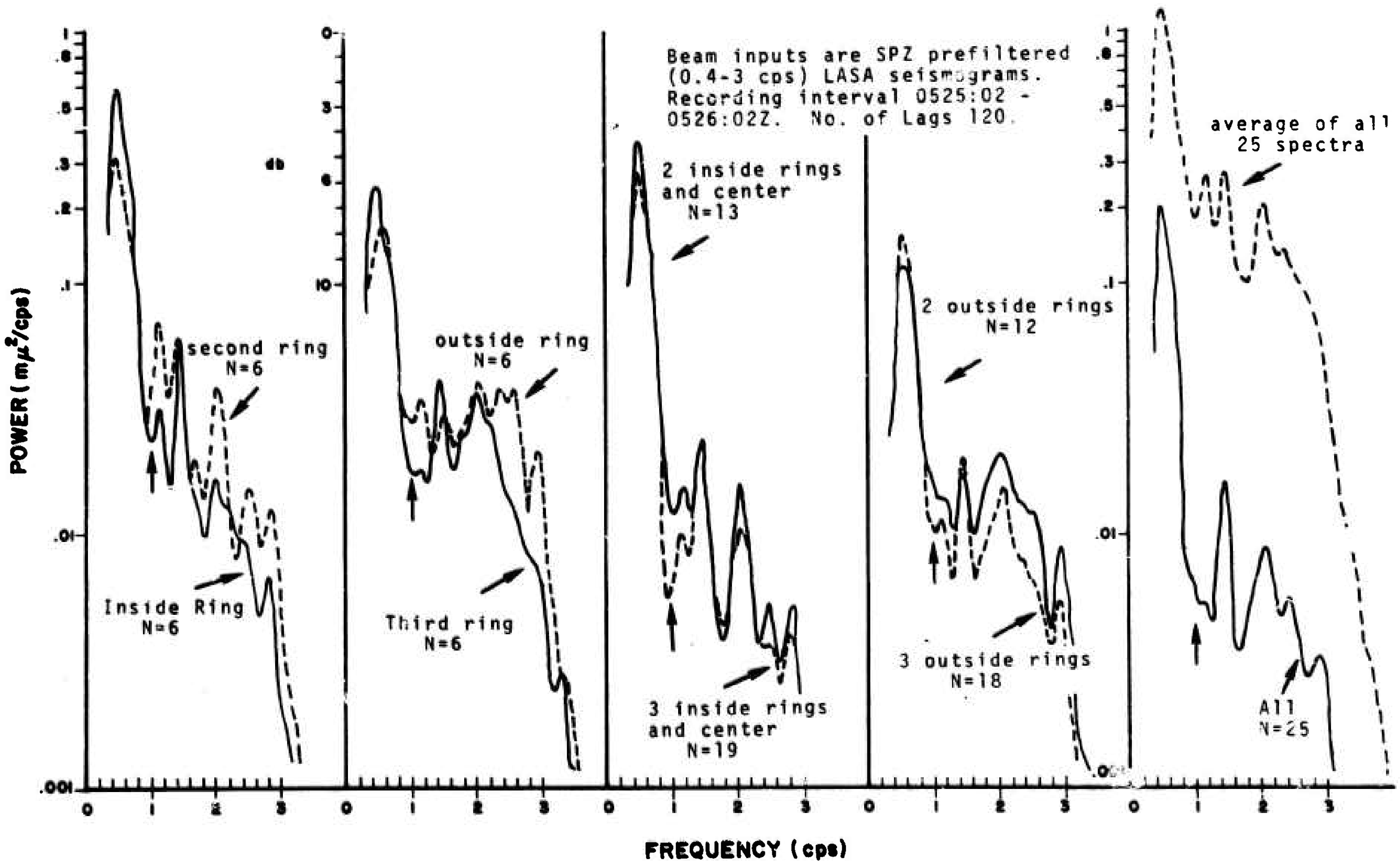

Figure 2 - Noise Power Spectra for E3 Beams - 08 March 1967

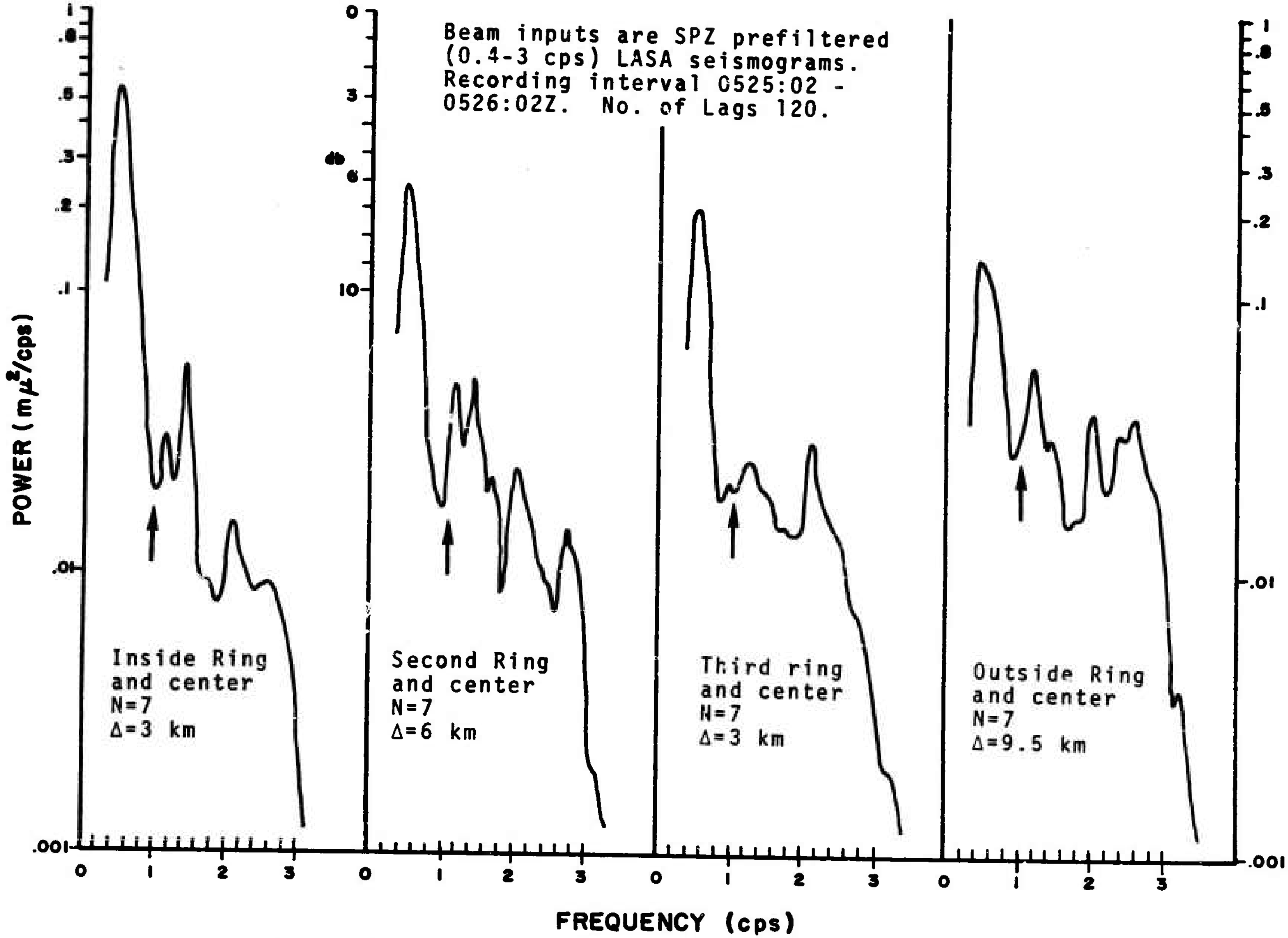

Figure 3 - Noise Power Spectra for 7-Element E3 Beams - 08 March 1967

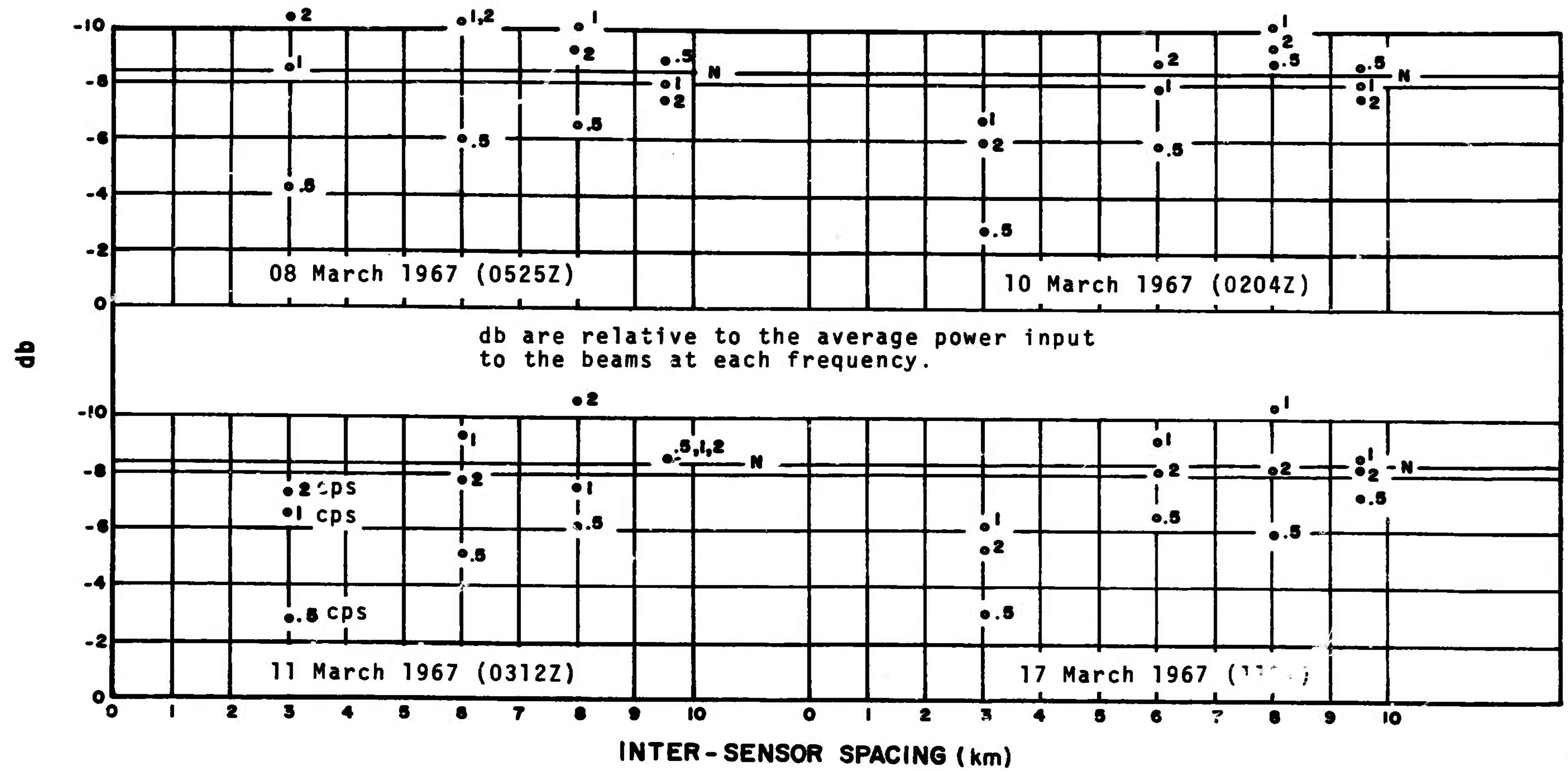

Figure 4 - Noise Power Reduction for 7-Element E3 Beams

Long-period Noise. We said above that our basic procedure was to beamsteer a fixed number of traces, N, while varying inter-sensor spacing, Δ . Table 1 shows that long-period sensor groups used here and corresponding approximate spacing intervals and beam apertures.

Our results are summarized in Figure 1 which shows average noise reduction, in db, as a function of sensor spacing, in kilometers, for two experimental methods. In the case of N=5 in Figure 1, both methods have reduced the noise nearly by a factor of $N^{\frac{1}{2}}$ at Δ = 20 km. On the other hand, for Δ = 30 km noise has been reduced by more than a factor of $N^{\frac{1}{2}}$. A similar result is observed for N=9, although in this case we were unable to form a beam for Δ = 20 km.

Conclusions

The following conclusions are based on beamforming studies which used short-period vertical-component seismograms recorded in the extended E3 subarray at the Montana LASA, as well as long-period vertical-component LASA data.

1. Short-period beams consisting of 18, 19, and 25 inputs from the E3 subarray have approximately the same noise level at 1 cps. This is due either to a higher average input noise level for the 25-element beam, or to the possibility of more highly correlated noise between the additional channels of the larger beam.

2. Seven-element E3 beams reduce noise power at 1 cps nearly by a factor of N for average adjacent-sensor spacings equal to or greater than 6 kilometers.

3. Long-period beams composed of either 5 or 9 vertical-component LASA seismograms reduce average input rms noise levels and average mean square noise by a factor of $N^{\frac{1}{2}}$ at sensor spacings greater than approximately 20-30 kilometers.

Table 1.
LPZ SENSOR GROUPS FOR N=5 AND N=9

N	SENSORS	≈ SPACING (KM)	≈ APERTURE (KM)
5	AO, B1-4	10	18
5	AO, C1-4	15	30
5	C2-4, D2-3	20	38
5	AO, D1-4	30	56
5	AO, E1-4	60	116
5	AO, F1-4	100	200
9	AO, B1-4, C1-4	10	30
9	AO, C1-4, D1-4	15	56
9	AO, D1-4, E1-4	30	116
9	AO, E1-4, F1-4	60	200

References

Hartenberger, R.A., and Shumway, R.H., 1967, "A Beamforming Study Using Outputs from the Extended E3 Subarray at the Montana LASA", Report No. 198, Seismic Data Laboratory, Teledyne, Inc., Alexandria, Virginia.

Hartenberger, R.A., 1967, "Power Spectra and Noise-Reducing Qualities of LASA Beams", Report No. 202, Seismic Data Laboratory, Teledyne, Inc., Alexandria, Virginia.

B. The Effect of the Number and Spacing of Elements on the Efficiency of LASA Beams

This analysis was conducted in support of the VELA Seismological Center in an attempt to evaluate the effect of the inter-sensor spacing on the efficiency of LASA beams. Specifically, we are interested in preserving the 200 km aperture while determining the amount of signal loss, rms noise reduction, and signal-to-noise gain which is produced by beamforming various combinations of LASA traces. Our basic procedures include prefiltering, time-shifting, and summing.

The data are short-period recordings of P waves from eight teleseismic earthquakes which occurred during the period 21 November 1965 to 22 April 1966. These events, which represent a subset of those reported earlier by Chiburis and Hartenberger (1966), are described in Table 2. Source parameters were taken from P.D.E. cards published by the USC&GS.

Procedure

Each seismogram used in this study was detrended to remove the mean, demagnified to convert digital counts to equivalent earth motion at 1 cps, and prefiltered to the band 0.4 - 3.0 cps. In forming the beams, subarray data were time-shifted to the earliest arrival on the basis of apparent phase velocity and station-to-epicenter azimuth. Array data were shifted by applying travel-time differences corrected by observed average travel-time anomalies, for each epicentral area.

EVENT NAME	DATE	ORIGIN TIME	LOCATION		OISTANCE		DEPTH IN KM	APPARENT VELOCITY	BACK AZIMUTH	CAL DATE	USC&GS m	NO. OF OUTPUTS USEO
			LAT	LONG	OEG	KM						
KURILE	21 Nov 65	06:10:56.0	48.4N	154.7E	62.1	6902	33	16.6	311.9	11/21/65	4.7	525
NO. COLOMBIA	21 Dec 65	12:25:43.0	06.9N	73.0W	48.8	5429	172	14.4	133.7	12/21/65	4.9	525
ALASKA PENN.	30 Oec 65	03:02:59.0	54.1N	160.2W	34.5	3831	33	12.9	302.6	12/30/65	4.5	525
SO. PERU	30 Oec 65	06:16:03.9	16.8S	71.2W	70.5	7854	118	18.2	144.4	12/30/65	5.7	525
CHIAPAS, MEX.	22 Jan 66	07:36:49.3	17.4N	94.1W	30.9	3434	139	12.6	157.0	1/22/66	4.9	525
HOKKAIOO	19 Mar 66	08:11:40.0	43.3N	145.8E	70.1	7794	11	18.1	312.4	3/19/65	5.6	525
NO. COLOMBIA	21 Apr 66	08:18:23.9	06.9N	73.1W	48.8	5424	152	14.4	133.8	4/21/66	4.8	525
KOOIAK	22 Apr 66	10:15:51.0	56.9N	151.8W	29.5	3275	33	12.6	307.2	4/22/66	4.9	525

Table 2. Source data

Signal amplitude is defined as half the maximum peak-to-trough amplitude occurring within an 8-second window. Noise amplitude is defined as the root-mean-square value obtained in a 50-second window ahead of the P arrival. Gains and losses, in decibels, are computed from the following formula:

$$\text{db} = 20 \log \left[\frac{\text{value on beam output}}{\text{average input}}\right]$$

Beams

Seismograms from one of the eight events, the 19 March 1966 Hokkaido earthquake, were beamformed six times. The beams were composed of 17, 34, 51, 68, 119, and 525 channels, corresponding to approximate minimum intersensor spacings, Δ, of 12, 6, 6, 3, 3, and 0.5 kilometers. Only 17 subarrays contributed traces to the beams; the four subarrays comprising the "B" ring have been eliminated. Moreover, aside from the number of elements in the beams, all parameters for signal alignment were held constant, e.g., phase velocity, azimuth, travel-time differences, anomalies, and the time windows of the signal and the rms noise, were not changed.

Recordings of each of the eight events shown in Table 2 were beamsteered twice by using 51 traces in the first beam and 525 channels in the second. In the case of the 51-element beam, three seismograms from each of the 17 subarrays were used. Minimum intersensor spacings for the 51 and 525-element beams were 6 kilometers and 0.5 kilometers, respectively. The amount of signal loss, rms noise reduction, and S/N produced by the events were averaged to obtain values which are discussed in the next section.

Results

Figures 5, 6, and 7 are plots of signal loss, rms noise reduction, and S/N gain resulting from beamforming the Hokkaido event. Each figure shows gain or loss in decibels as a function of the number of beam inputs, N. As shown in Figure 5, the signal loss is 2 db for the 17-element beam, whereas the amount of signal loss for beams containing 34 or more traces is 3 db. This infers that imprecisions in beamforming the entire LASA are more significant than the inaccuracies resulting from time-shifting subarray data.

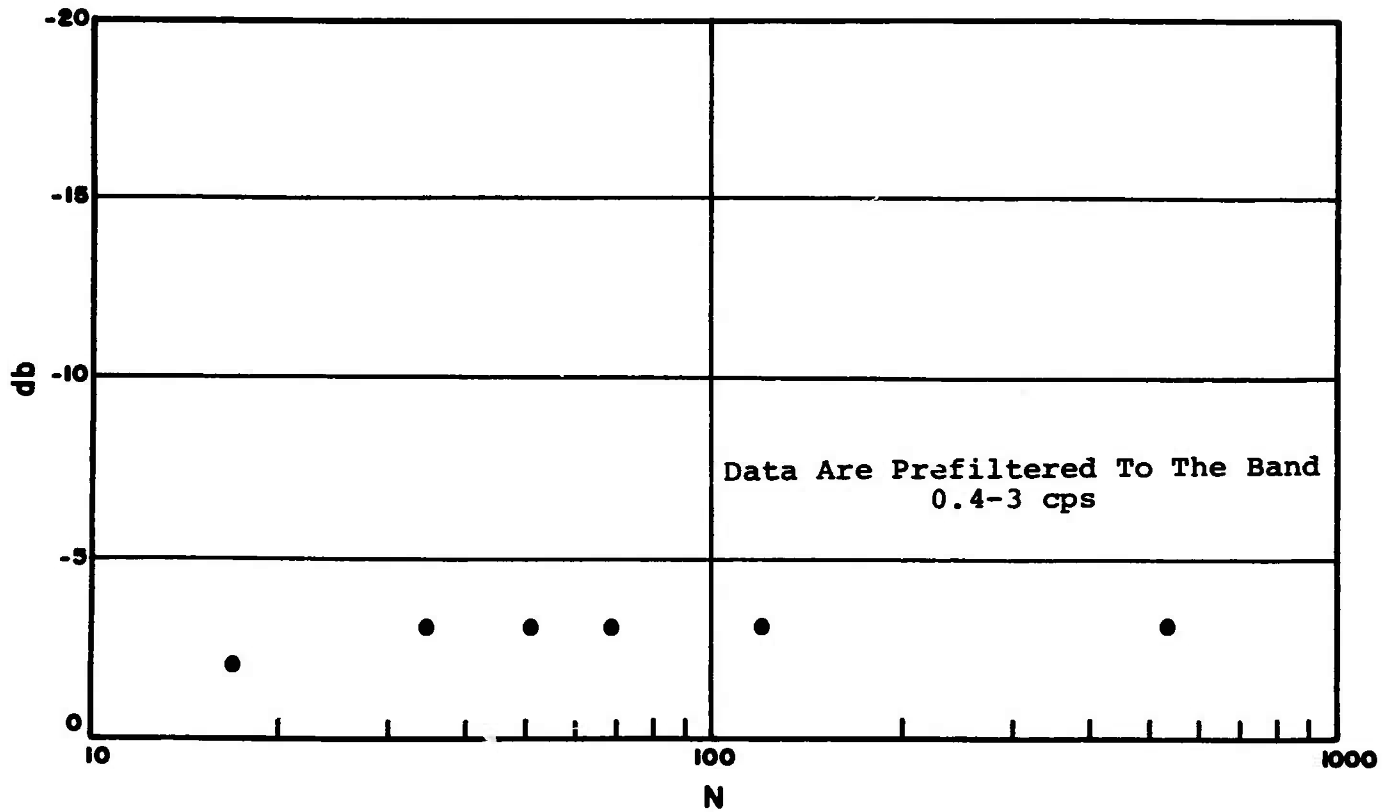

Figure 5. Signal Loss by Beamforming LASA Recordings Of The 19 March 1966 - Hokkaido Earthquake

Figure 6, which shows rms noise reduction as a function of N for the Hokkaido event, illustrates that N increases as Δ decreases, the amount of noise reduction becomes less favorable relative to $N^{\frac{1}{2}}$. In fact, the advantage of the 525-element beam with respect to the much smaller 51-element beam is only 1 db. Moreover, the 119-trace beam performs equally as well as the largest beam.

S/N gain as a function of N for the Hokkaido earthquake is shown in Figure 7, in which the results reflect the combined effect of signal loss and noise reduction as discussed above; our interpretation need go no farther.

Figures 8 through 10 are plots of average values for signal loss, rms noise reduction, and S/N gain, as a function of N. We repeat that these values represent average results obtained from our set of eight events. The average signal loss shown in Figure 8 is about 4 db for both the 51-element and 525 element beams.

The average noise reduction produced by beamforming 51 channels, Figure 9, is very close to $N^{\frac{1}{2}}$ and only 1 db less than that produced by the larger beam. Again we see that the combined effect of increasing N and simultaneously reducing Δ to values less than 6 km is to produce less noise cancellation relative to $N^{\frac{1}{2}}$. Previous work (Hartenberger and Shumway 1967) has shown that for spacing of 6 km or more, the short-period noise at LASA is essentially incoherent.

As shown in Figure 10, S/N gain yielded by beaming 51 traces is only 1 db less than that produced by beamforming all 525 channels.

Figure 11 shows the rms noise level, in mμ , as a function of event number. The solid dots represent values taken from outputs of 525-element beams, while the open circles are corresponding values for the smaller beam. The average noise level on the larger beam is 0.21 mμ , whereas the smaller beam average is 0.25 mμ .

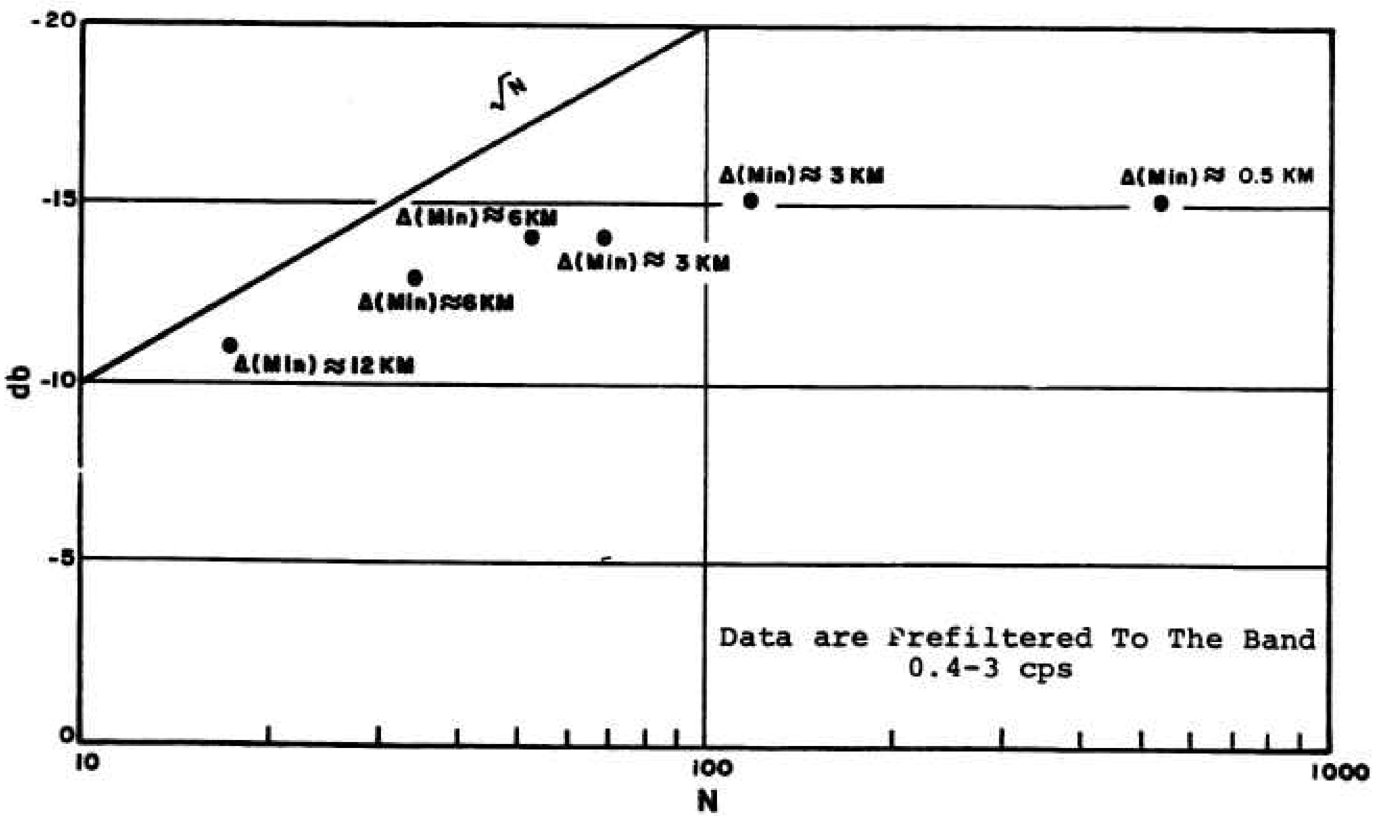

Figure 6. RMS Noise Reduction by Beamforming LASA Recordings Of The 19 March 1966 Hokkaido Earthquake

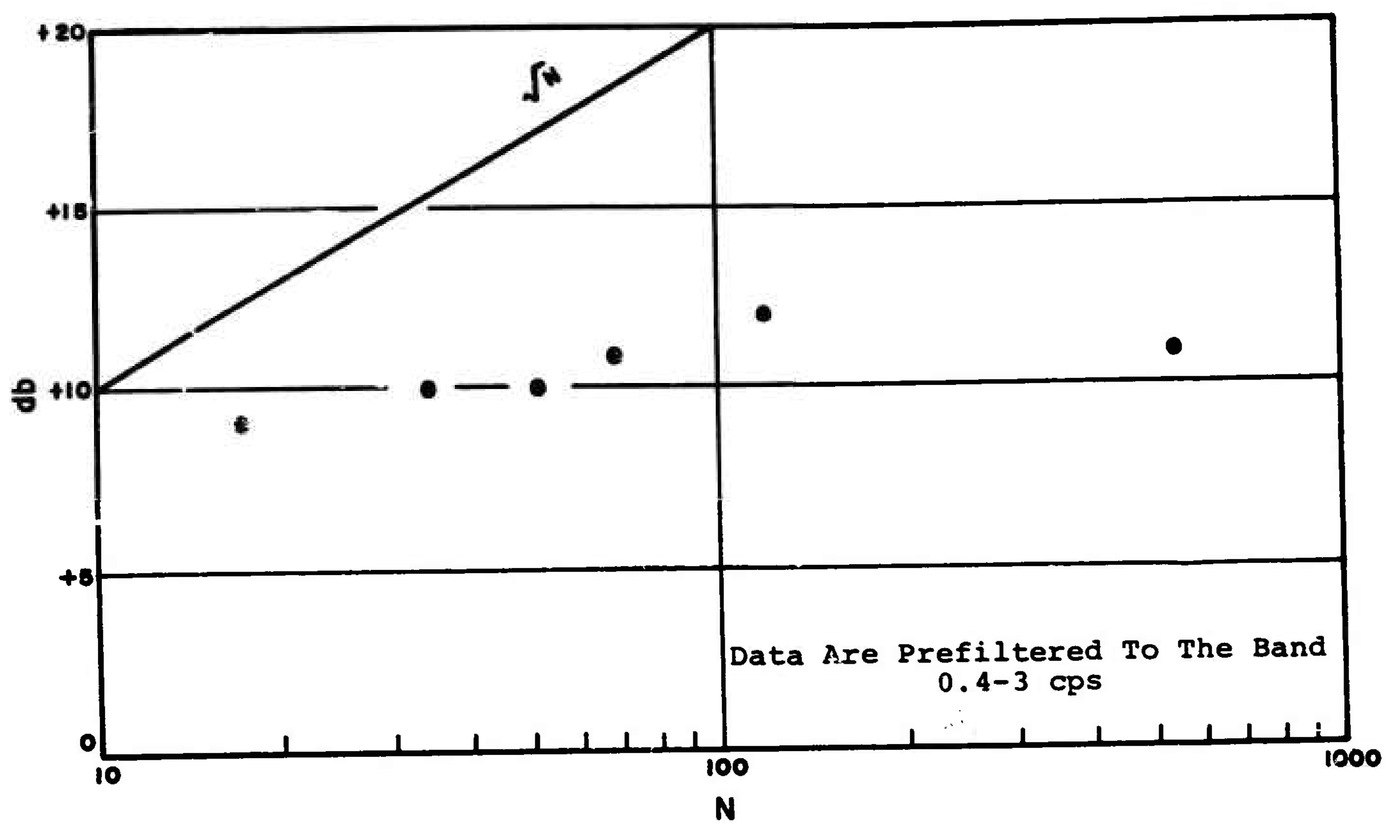

Figure 7. S/N Improvement by Beamforming LASA Recordings Of The 19 March 1966 Hokkaido Earthquake

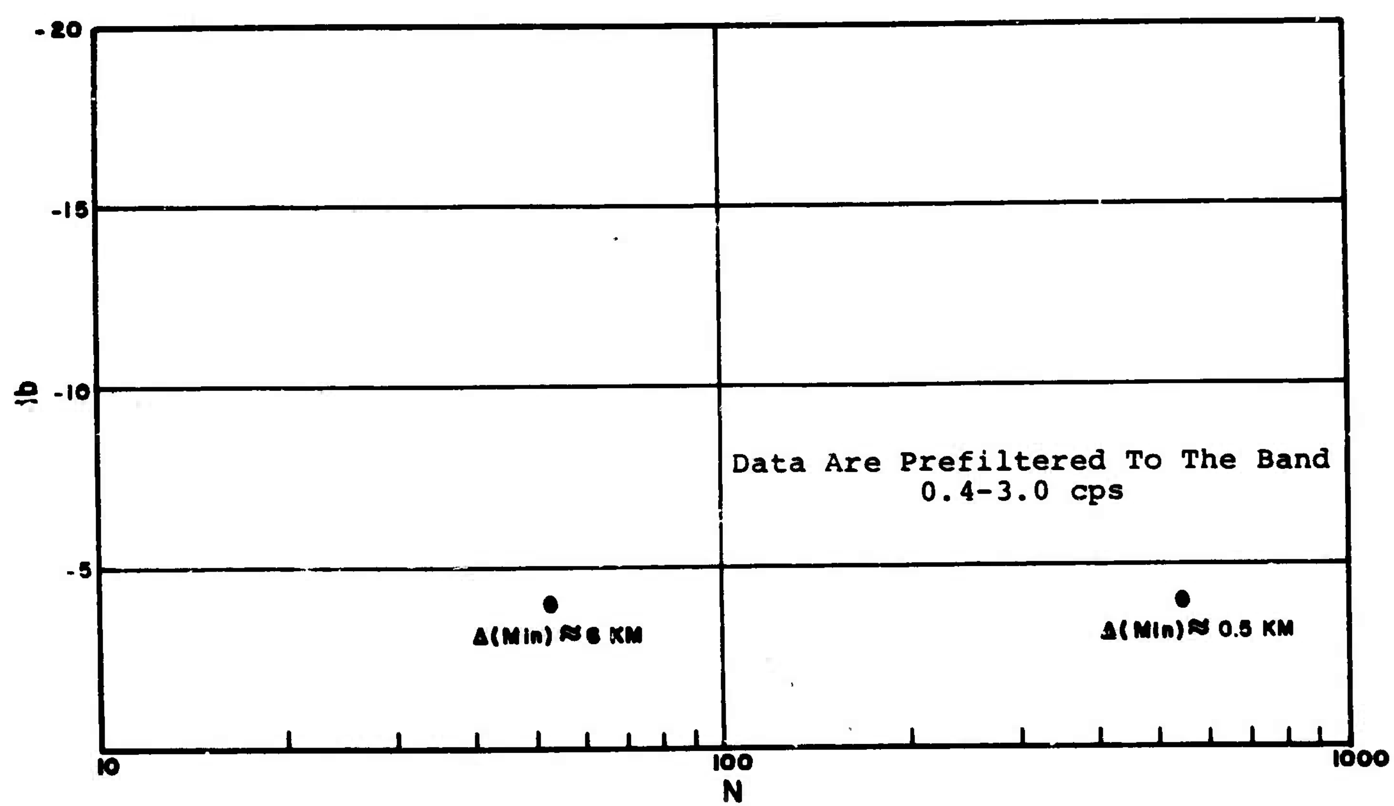

Figure 8. Average Signal Loss by Beamforming LASA Seismograms

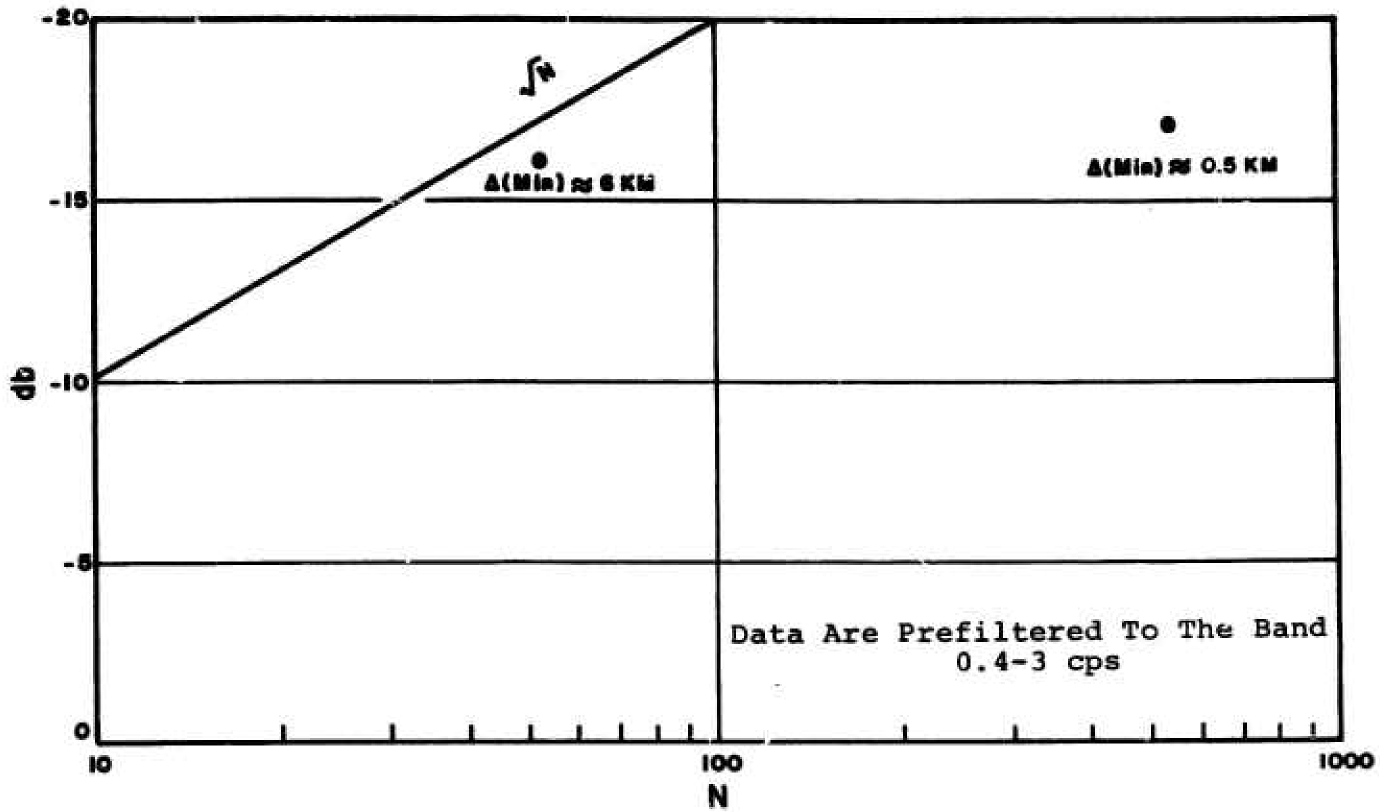

Figure 9. Average RMS Noise Reduction by Beamforming LASA Seismograms

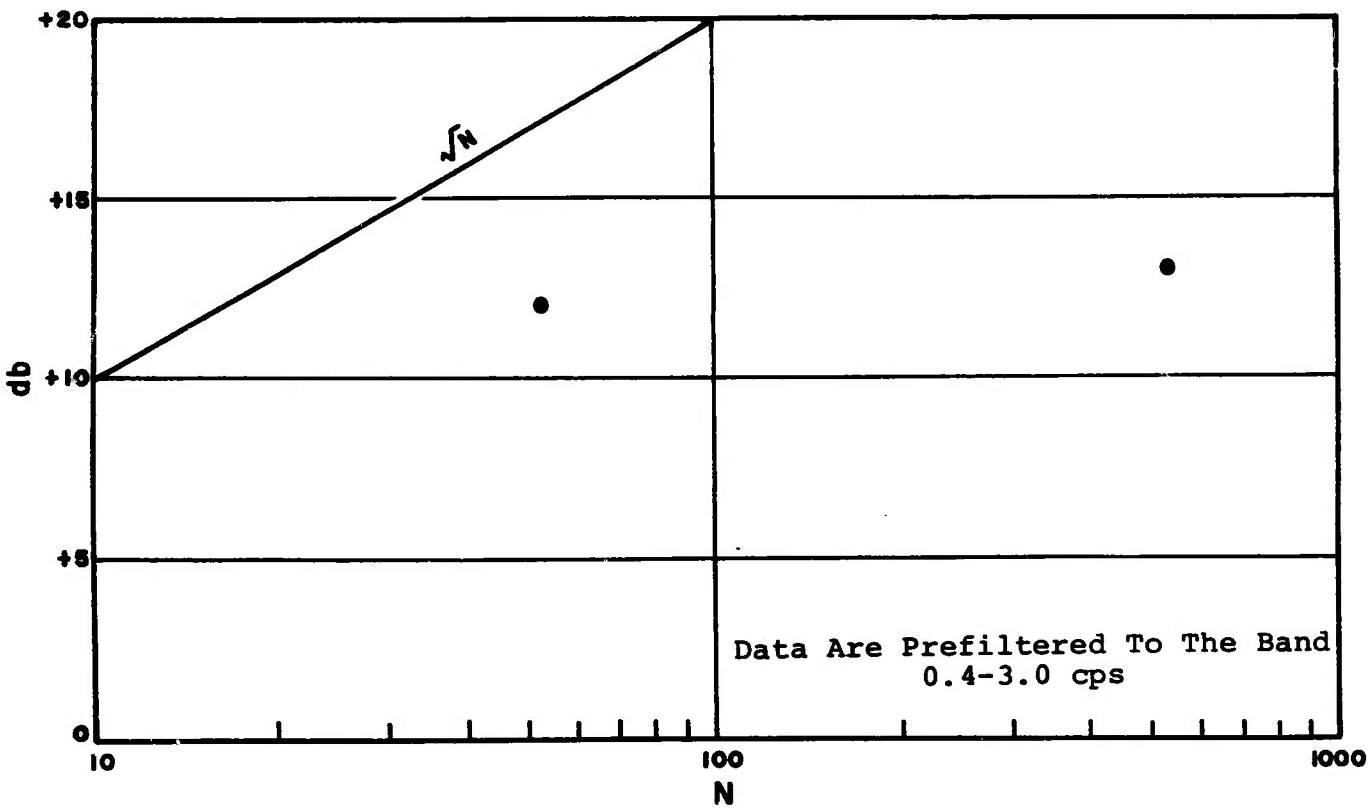

Figure 10. Average S/N Improvement by Beamforming LASA Seismograms

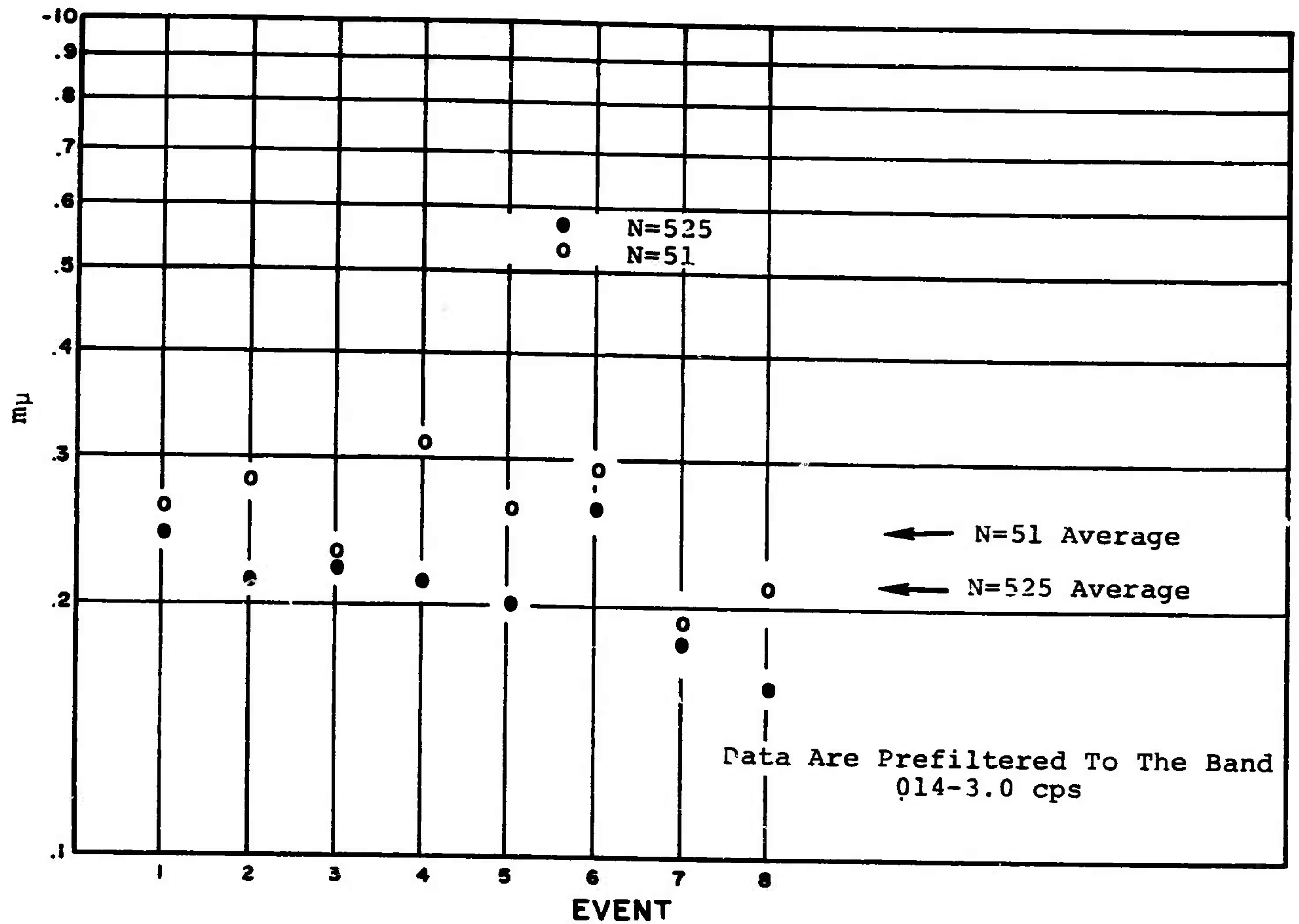

Figure 11. RMS Noise Levels on LASA Beams

Conclusions

In an SDL study LASA prefiltered short-period recordings of 8 teleseismic events were beamsteered on the P arrival using a variable number of beam inputs. Our objective was to determine the efficiency of the beams with respect to the number of inputs and the spacing of sensors contributing to the beams. The following conclusions are based on that analysis:

1. The net effect of increasing the number of beam inputs while simultaneously decreasing sensor spacing is to produce progressively less rms noise reduction and S/N gain, relative to $N^{\frac{1}{2}}$.

2. Average signal loss amounts to 4 db. We attribute part of the loss (1 db?) to misalignment of P waves within subarrays. The remaining signal loss is due either to inaccurate array alignment or to differences in wave form across the LASA.

3. Beams composed of 51 traces reduce rms noise and improve S/N within 1 db of that produced by 525-element beams. The 51 elements were selected to have minimum sensor spacing greater than 6 km.

References

Chiburis, E.F. and Hartenberger, R.A., 1966, "Signal-to Noise Ratio Improvement by Time-Shifting and Summing LASA Seismograms", Report No. 164, Seismic Data Laboratory, Teledyne Incorporated, Alexandria, Virginia.

Hartenberger, R.A. and Shumway, 1967, "A Beamforming Study Using Outputs from the Extended E3 Subarray at the Montana LASA", Report No. 198, Seismic Data Laboratory, Teledyne Incorporated, Alexandria, Virginia.

Hartenberger, R.A., 1967, "The Effect of the Number and Spacing of Elements on the Efficiency of LASA Beams", Report No. 203, Seismic Data Laboratory, Teledyne Incorporated, Alexandria, Virginia.

C. Frequency-Wave Number Analysis of Signals and Noise Recorded at the UBO Vertical Array

This is one of a series of observations of teleseismic signals and noise at vertical array sites. The purpose is to compare the f-k spectrum of noise preceding the signal and the signal-generated noise following the signal, with a teleseismic signal. Another objective is to note any anomalous characteristics of the signal which may significantly affect the design of vertical array filters.

Procedure

The Uinta Basin Observatory (UBO) vertical array site is in a quiet ambient seismic noise environment located in an inter-mountain basin in Utah. The average structure as observed by an ultrasonic well survey of the compressional velocity is primarily a nearly uniform gradient between 3 km/sec and 6 km/sec at 5.7 km depth. For the deepest sensor (2.71 km), the theoretical uphole time is .716 sec., indicating an average velocity of 3.8 km/sec.

The Fiji Island event which was analyzed was recorded on 30 December 1966. The USC&GS depth of focus was 658 km, magnitude 5.0, and approximate distance of propagation was 85°.

The sensor depths are 1.13, 1.49, 1.80, 2.11, 2.47, and 2.71 km. The sample of noise before the signal consisted of 2048 points sampled at the rate of 20 points per second. Samples of 128 points and 256 points were taken about the largest pulse characterizing the P wave received from the Fiji earthquake event. The coda following the signal was sampled with 1024 points immediately following the signal window.

The SDL program for computing f-k spectra makes use of the fast Fourier transform to compute average power as a function of frequency and wave number. Averages were based on time integration with approximately 4 degrees of freedom per estimate for the noise sample of 1024 points and 8 degrees of freedom for the ambient noise sample of 2048 points.

Results

The f-k spectrum of the ambient noise preceding the signal is shown on Figure 12. The principal noise peak occurs at .16 cps with the high frequency noise nearly centered about the k=0 axis. This suggests that the ambient noise consists predominantly of energy in trapped modes. The slight asymmetry in the wave number pattern suggests a net flow of energy downwards, possibly due to beds dipping roughly 5°. The asymmetry is more evident in the 1.85 cps peak. There is no substantial evidence of reflected P-pulses, although such a component may be obscured by the array response. The main peak of the signal is shown on Figure 13. The apparent down-going velocity is 4.51 km/sec and apparent up-going velocity is 4.0 km/sec. This anomaly may be due to reflection from a slightly tilted earth's surface, or to dipping beds or other structural complexities.

The f-k analysis of the signal coda is shown on Figure 14. It differs from both the signal peak and noise preceding the signal by the striking asymmetry in the 1.0 to 1.75 cps band indicating a net upflow of energy and an abundance of conversion phenomena, as compared to the near f-k symmetry shown for the preceding samples. The apparent down-going velocity of body waves in the coda is 4.8 km/sec and that of the up-going waves is 4 km/sec which is similar to the peak signal. The relative up and down peak amplitudes and peak frequency in the coda are approximately the same as that of the peak pulse.

References

Sax, R.L., 1967, Frequency-Wavenumber Analysis of Signals and Noise Recorded at the Vertical Array at Apache, Oklahoma, Report No. 196, Seismic Data Laboratory, Teledyne Incorporated, Alexandria, Virginia.

Sax, R.L., 1967, Stability of Frequency-Wavenumber Noise Spectra at UBO, Report No. 197, Seismic Data Laboratory, Teledyne Incorporated, Alexandria, Virginia.

Sax, R.L., 1967, Frequency-Wavenumber Analysis of Signals and Noise Recorded at the UBO Vertical Array, Report No. 201, Seismic Data Laboratory, Teledyne Incorporated, Alexandria, Virginia.

VFKSPTRM

SEISMOGRAM NO. = [illegible]   NO. OF CHANNEL = 6

SAMPLING RATE = [illegible]   STARTING POINT = 1   TOTAL POINTS = [illegible]

THE NUMBER OF SMOOTHING TIME = 4

CHANNEL ID	SCALE FACTOR	DEPTH		SYMBOL
[illegible]	1.00	1.130	[illegible]	
[illegible]	1.00	1.490	[illegible]	[illegible]
[illegible]	1.00	1.000	[illegible]	[illegible]
[illegible]	1.00	0.119	10 - 19	[illegible]
[illegible]	1.00	2.470	10 - [illegible]	[illegible]
[illegible]	1.00	0.710	[illegible]	[illegible]

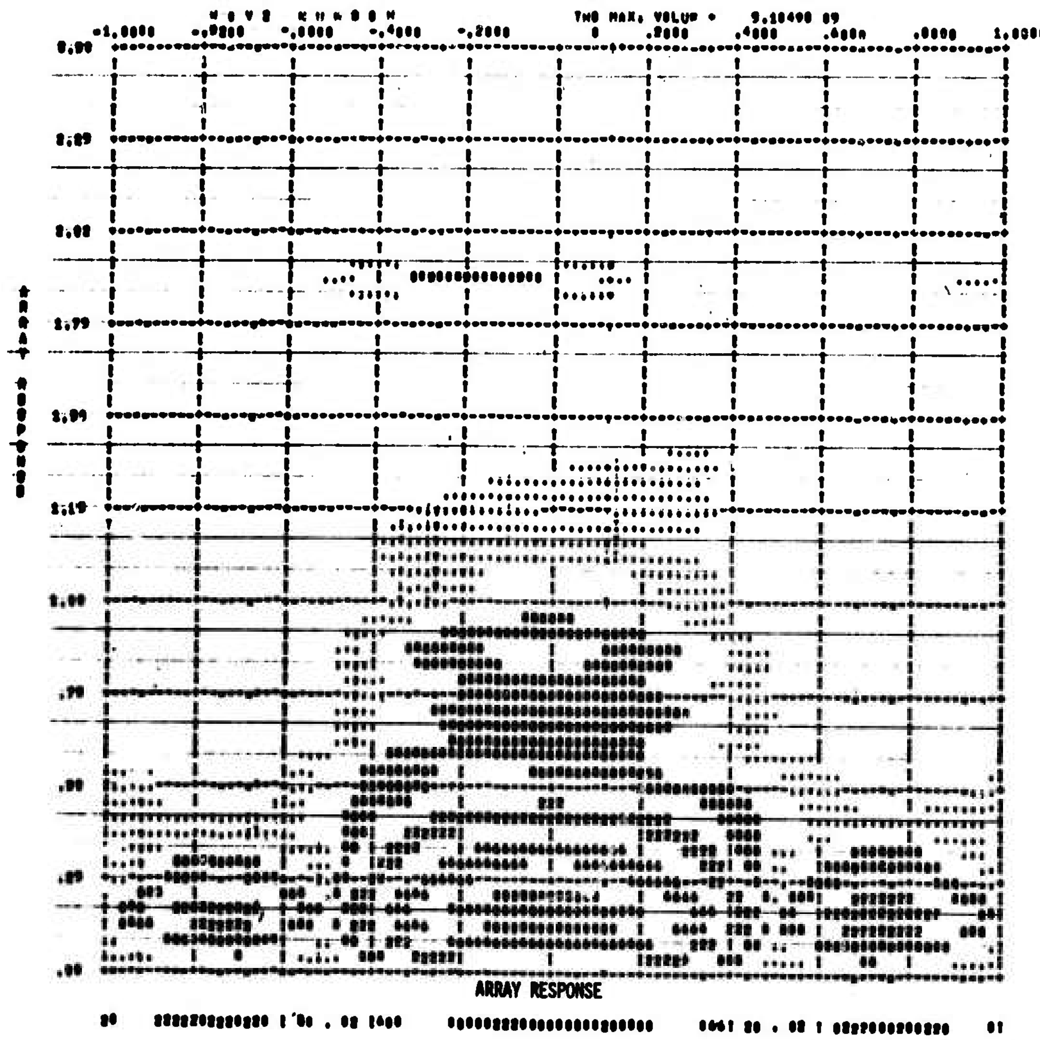

Figure 12. Noise Preceding Fiji Signal, UBO Vertical Array

VFKSPTRM

SEISMOGRAM NO. = 10141 NO. OF CHANNEL = 6

SAMPLING RATE = 20.00 STARTING POINT = 3000 TOTAL POINTS = 120

THE NUMBER OF SMOOTHING TIME = 0

CHANNEL ID	SCALE FACTOR	DEPTH	U S	SYMBOL
DW6	1.00	1.130		
DW5	1.00	1.490	0 - 3	0
DW4	1.00	1.000	0 - 9	[illegible]
DW3	1.00	0.110	10 - 15	2
DW2	1.00	0.470	18 - 21	8
DW1	1.00	2.710	24 - 27	[illegible]

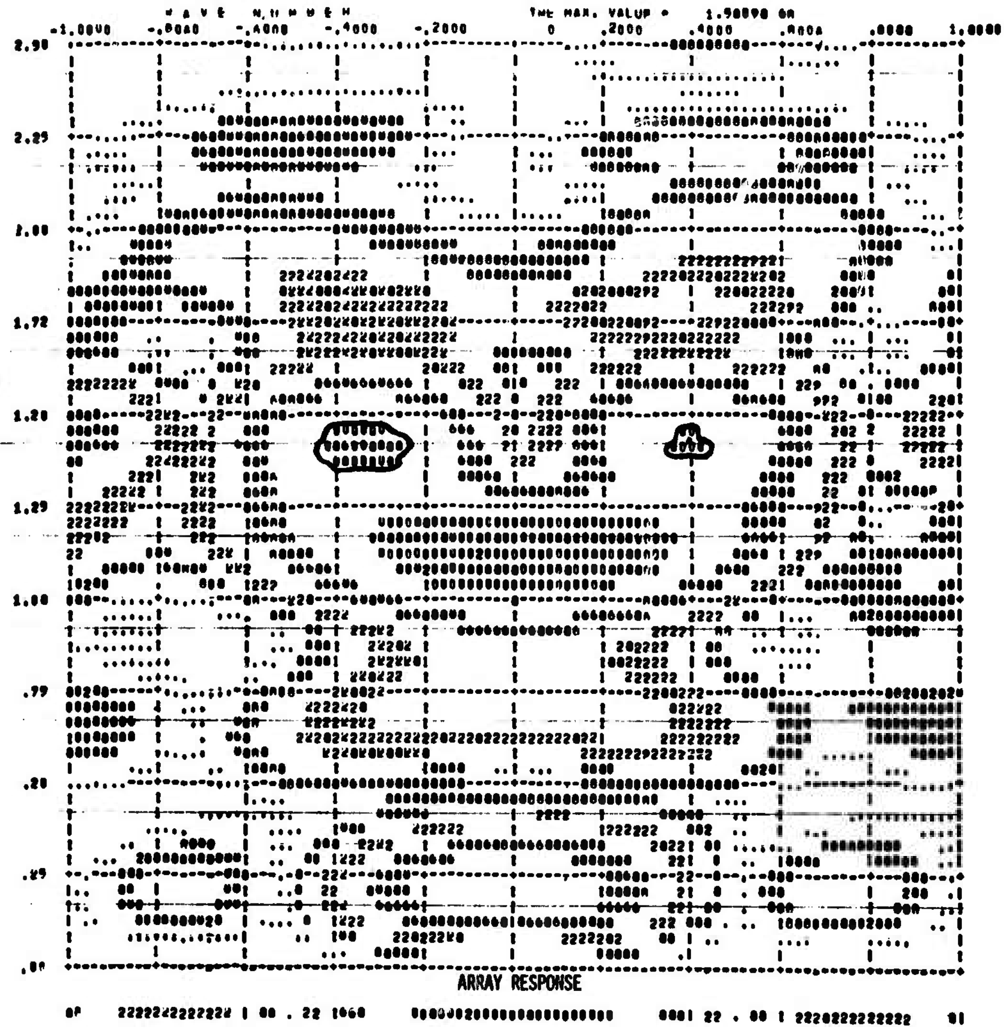

Figure 13. Fiji Signal, UBO Vertical Array

VFKSPTRM

SEISMOGRAM NO. = [illegible]   NO. OF CHANNEL = 6

SAMPLING RATE = 20.00   STARTING POINT = 4000   TOTAL POINTS = 1024

THE NUMBER OF SMOOTHING TIME = 0

CHANNEL ID	SCALE FACTOR	DEPTH	D D	SYMBOL
SW6	1.00	1.130		
SW9	1.00	1.490	0 - 8	0
SW4	1.00	1.000	[illegible]	[illegible]
SW2	1.00	0.110	10 - 15	0
SW2	2.00	0.470	18 - 21	0
SW1	1.00	0.710	24 - 27	[illegible]

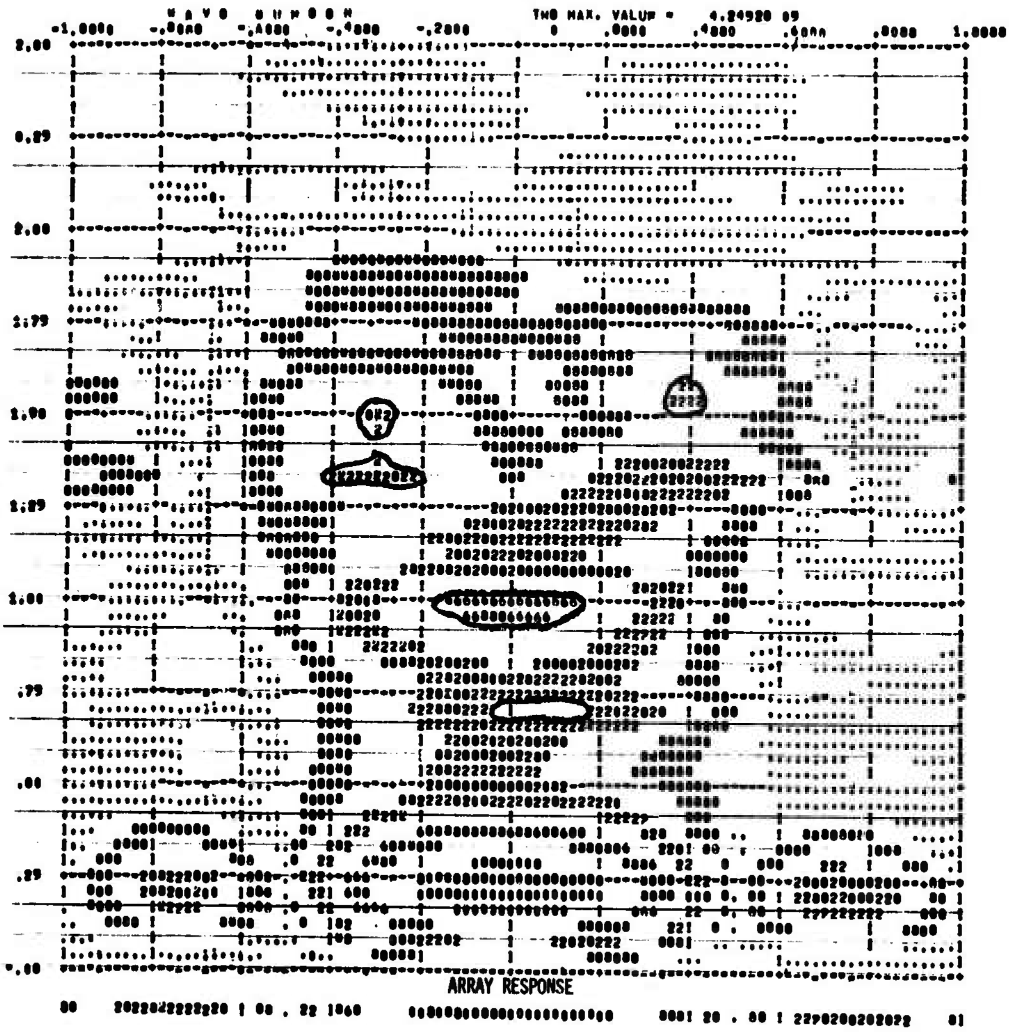

Figure 14. Coda of Fiji Signal, UBO Vertical Array

D. TFSO Long-Period L-Array Noise Coherence

During the period from about 01 February 1967 to 06 April 1967, a six-element array of long period seismographs was operated in the vicinity of the Tonto Forest Seismological Observatory in Arizona. The L-shaped array was composed of two legs bearing ENE and SSE with lengths approximately 25 km and 15 km respectively (Figure 15). Each of the sites contained three-component Geotech Model 7505A vertical and 8700C horizontal seismometers (free periods of 20 sec); photo-cell amplifiers were at all sites except TFSO which has a standard photo-tube amplifier.

The purpose of the array was to record and analyze the spatial properties (coherence) of long-period noise in the vicinity of TFSO with a view towards installing a permanent long-period 46 km hexagonal array of seven elements.

Ordinary Coherence

Noise samples from three different time periods were used for computing ordinary coherence. These samples, designated "Noise Sample #1" through "Noise Sample #3", are from the following time periods:

Noise Sample #1 - 25 February 67	0801Z
Noise Sample #2 - 26 March 1967	1025Z
Noise Sample #3 - 05 April 1967	1330Z

Noise Sample #1. This sample contains 4000 points digitized (by Geotech) at two points per second and prefiltered with a bandpass of 0.01 cps to 0.30 cps (half-power) with 18 db/octave rolloff. The ordinary coherences vs. frequency between all pairs of seismometers are shown in Figures 16 through 19. These coherences were obtained using a lag window of 50 points. As shown on these figures, the site PY-5 appears to have noise which is incoherent with the other sites. It is believed that there were no instrumental difficulties with this site (data are normal, visually, and the autospectrum agrees with the spectra from the other sites, as shown in Figure 20 so that the noise at this site is perhaps due to local winds, site emplacement properties, etc. Subsequent noise coherences from different times will be shown which indicate similar properties at PY-5 and to a lesser extent at PY-4 and PY-3.

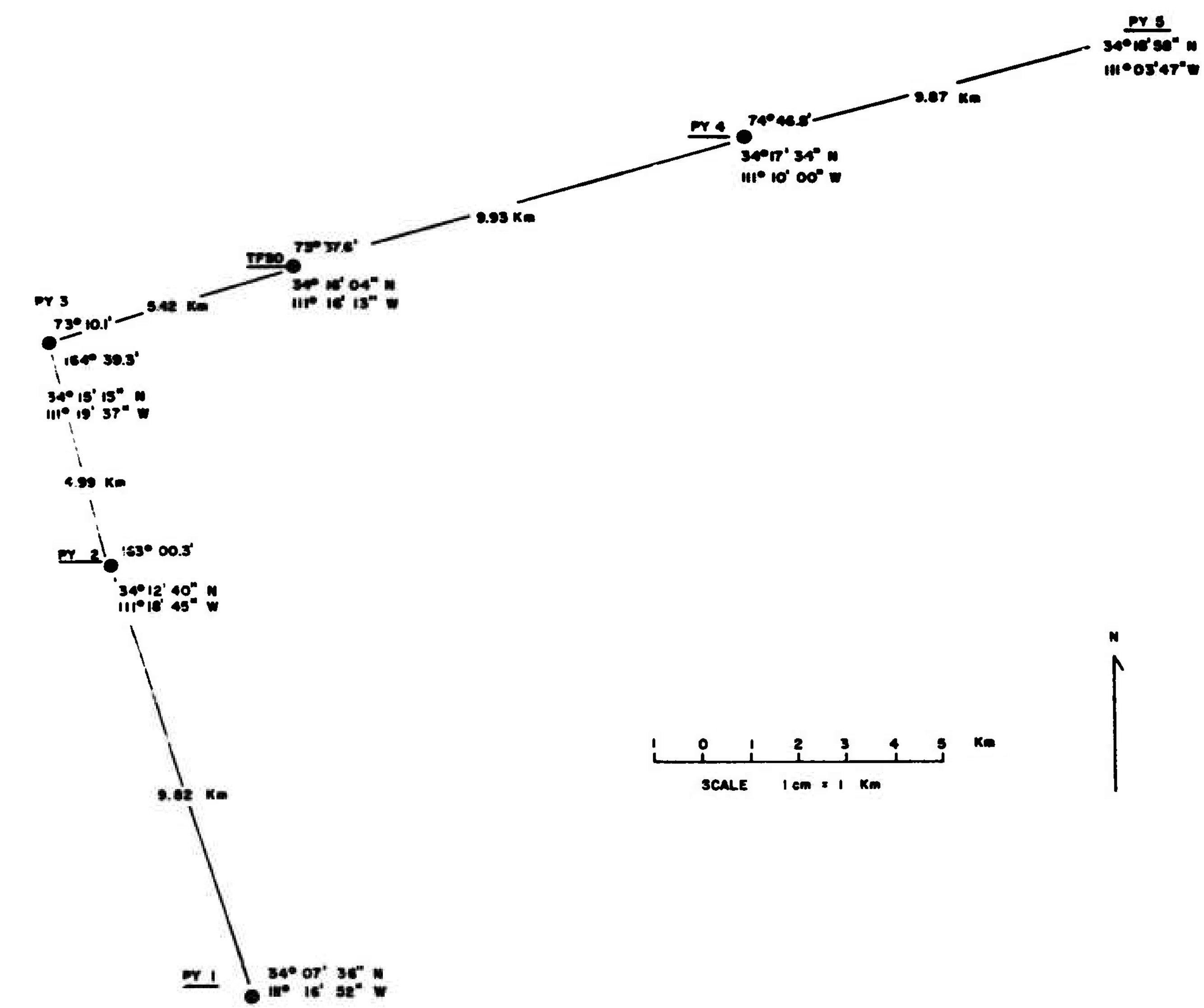

FIGURE 15. LOCATION MAP OF THE TFSO L-ARRAY.

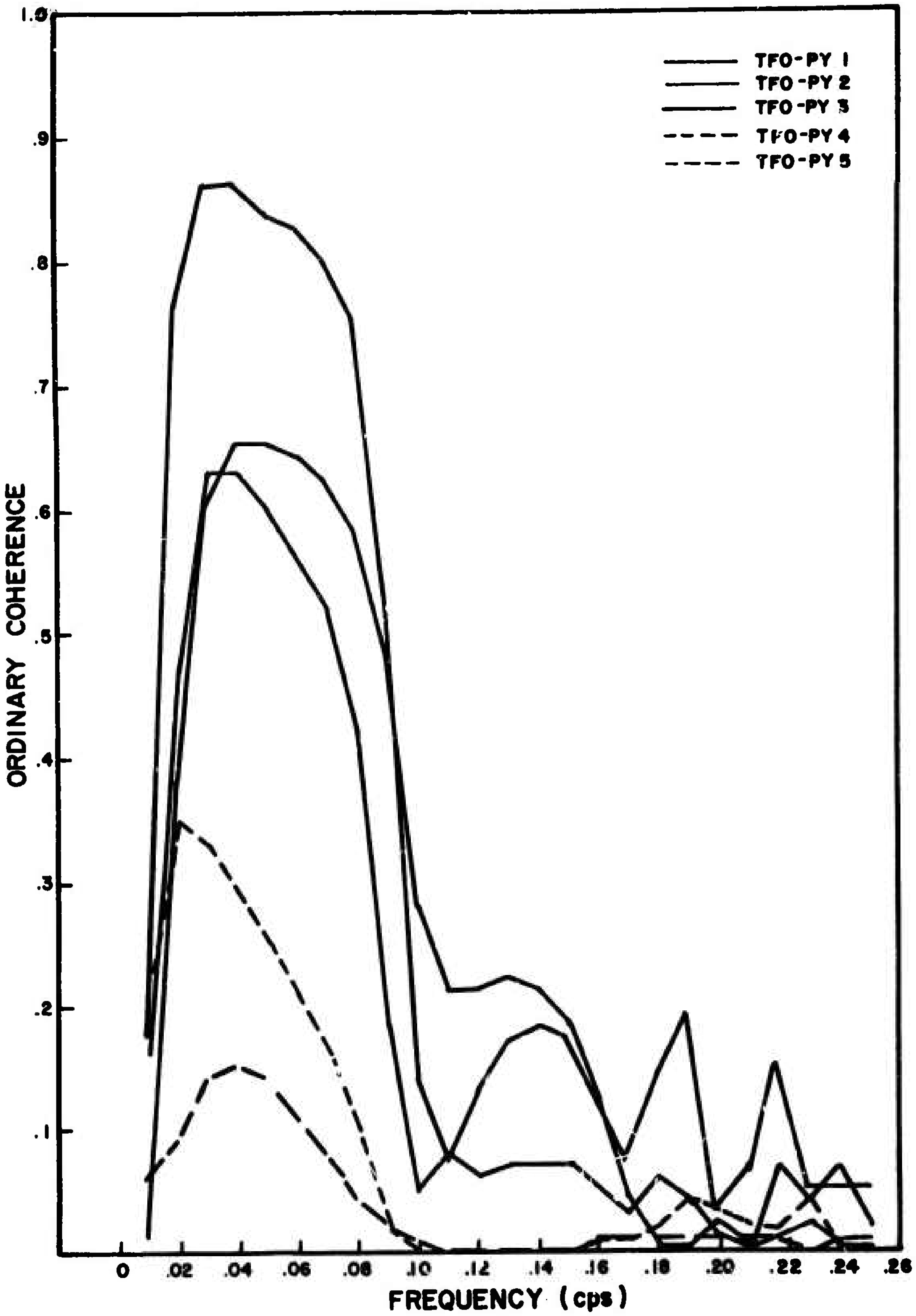

FIGURE 16. ORDINARY COHERENCE BETWEEN TFO AND PY1, PY2, PY3, PY4, PY5. NOISE SAMPLE #1.

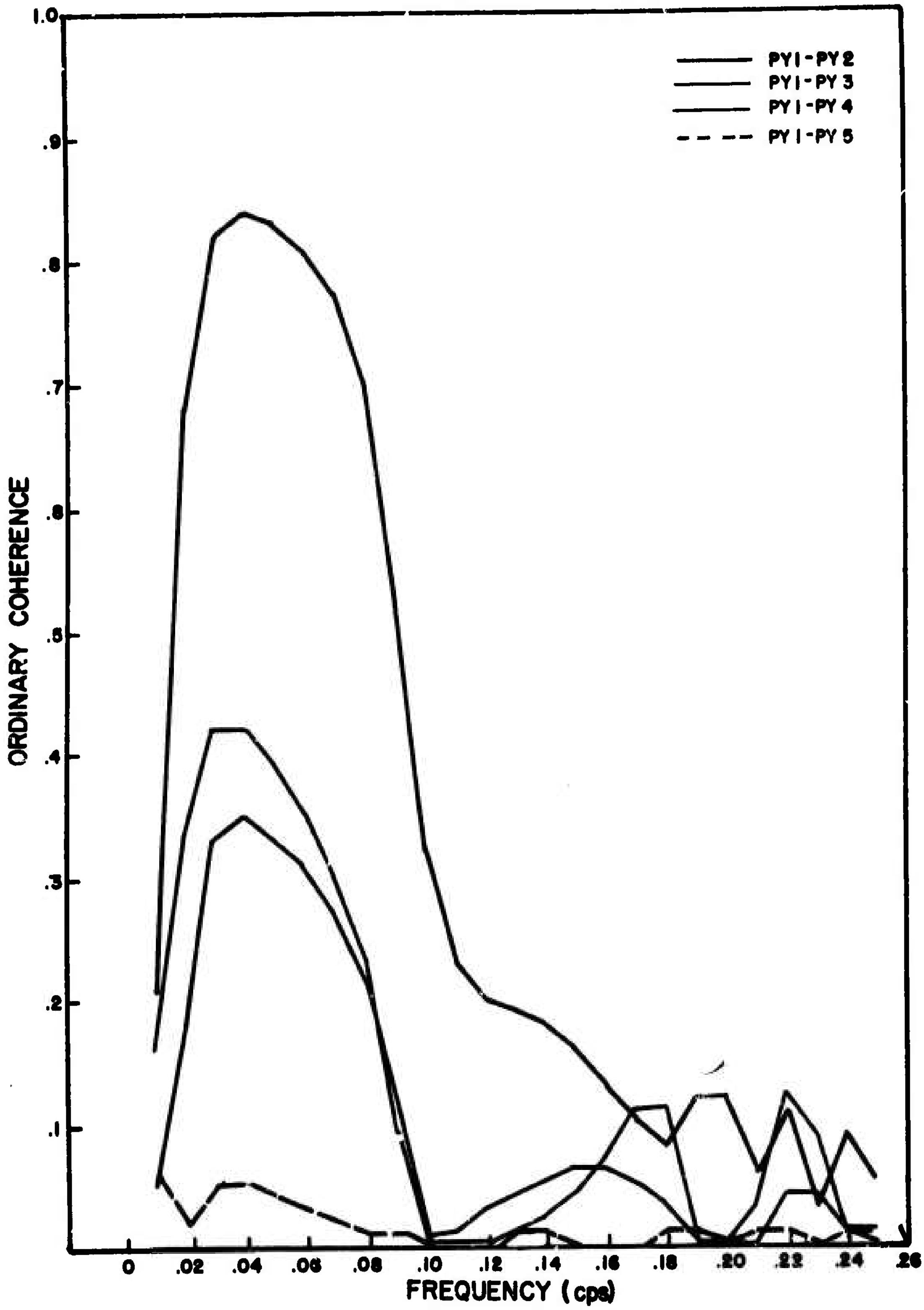

FIGURE 17. ORDINARY COHERENCE BETWEEN PY1 AND PY2, PY3, PY4, PY5. NOISE SAMPLE #1.

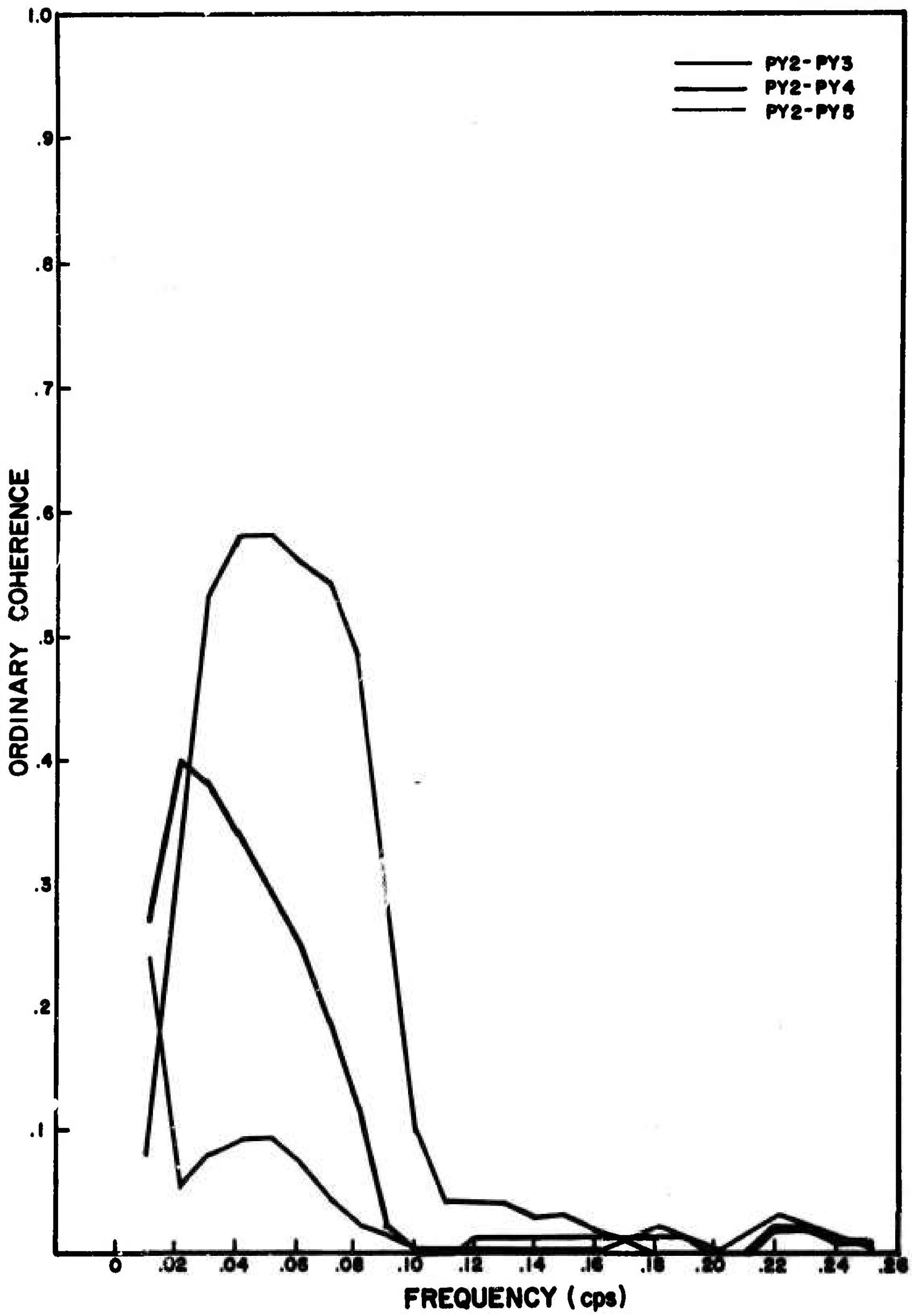

FIGURE 18. ORDINARY COHERENCE BETWEEN PY2 AND PY3, PY4, PY5. NOISE SAMPLE #1.

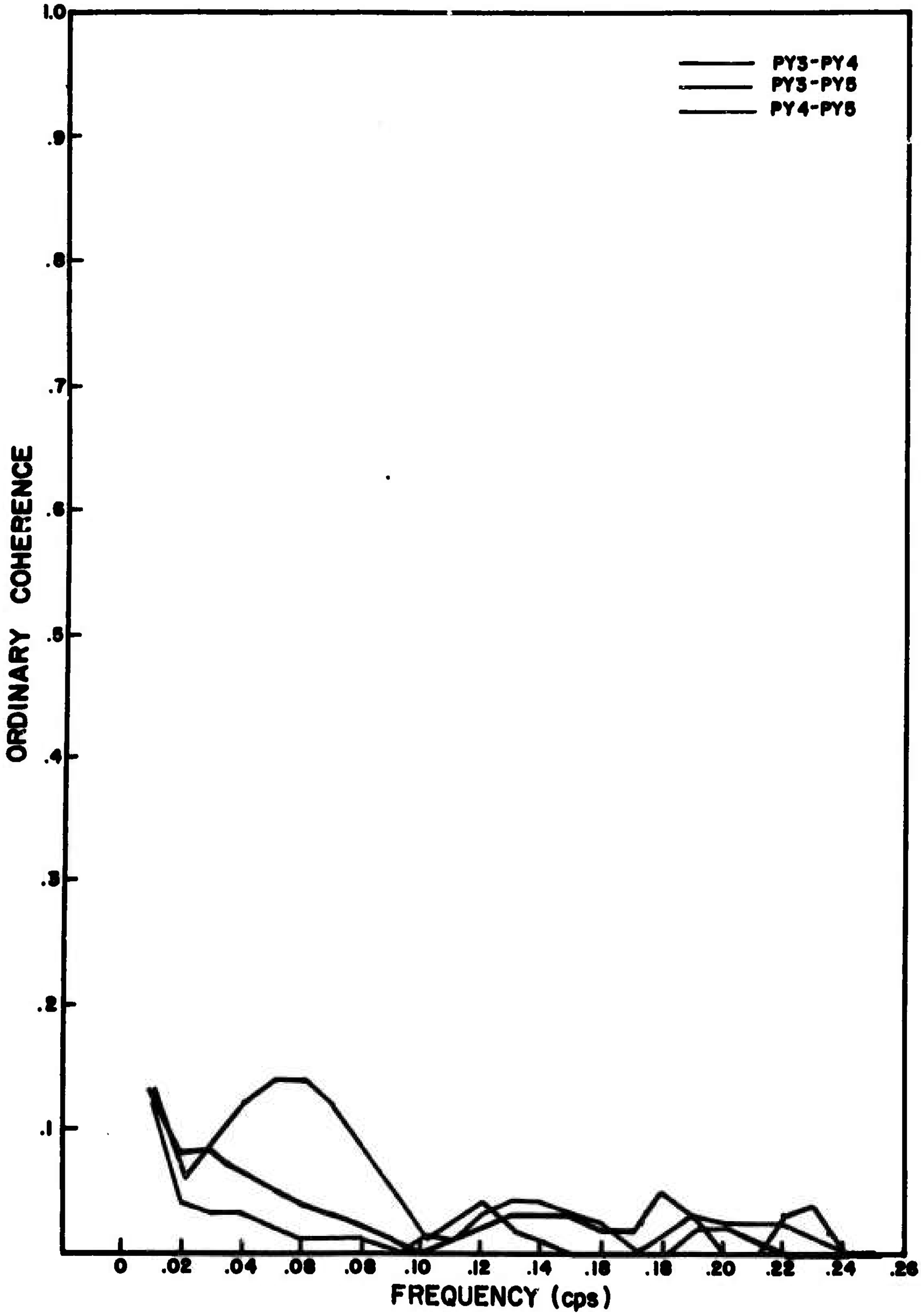

FIGURE 19. ORDINARY COHERENCE BETWEEN PY3 AND PY4, PY5 AND BETWEEN PY4 AND PY5. NOISE SAMPLE #1.

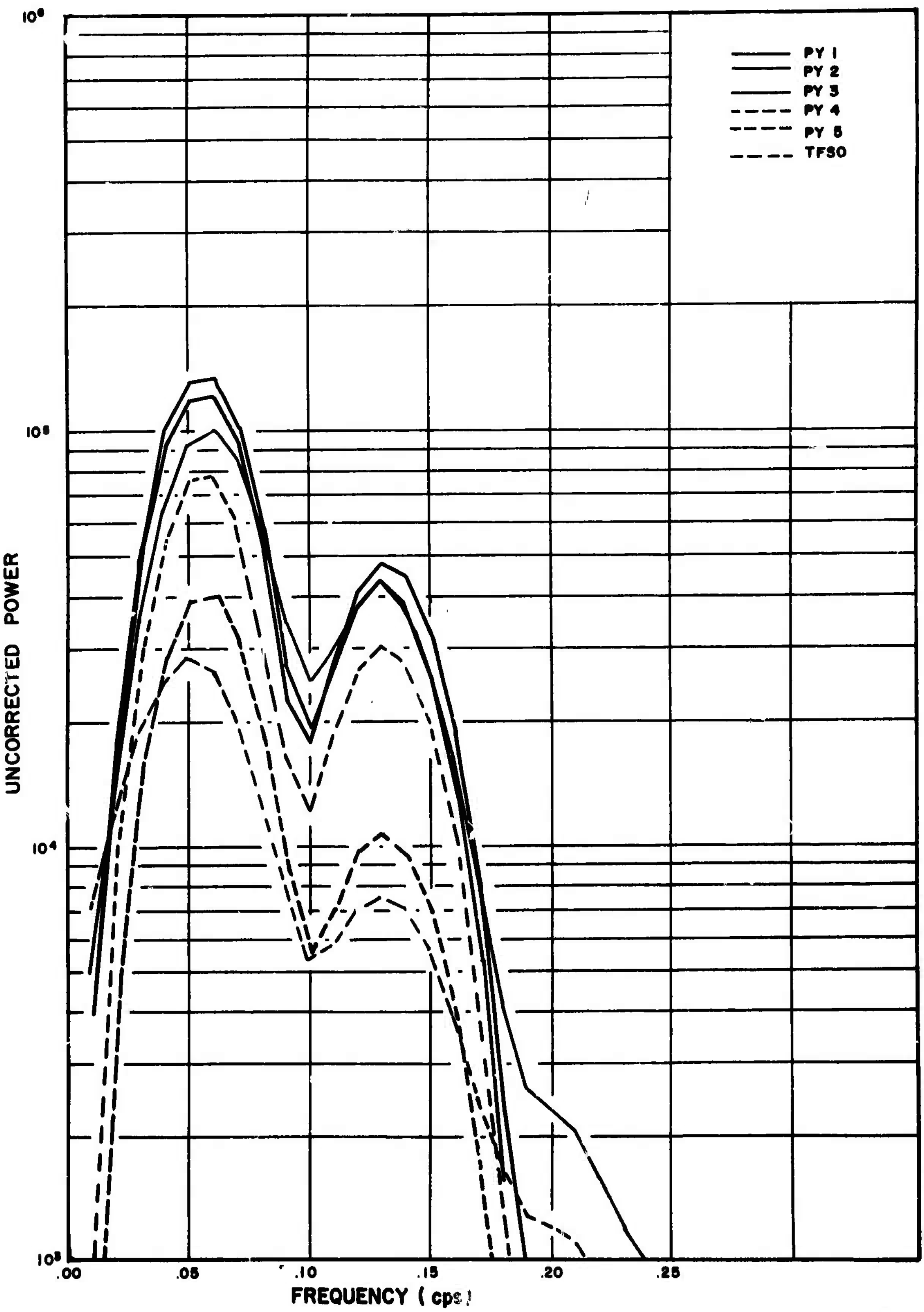

FIGURE 20. POWER SPECTRA AT THE TFSO L-ARRAY FOR NOISE SAMPLE #1.

Additional coherences were computed from the same data with longer lags (200 and 400 lags) but no significant changes in the coherences occur.

Noise Sample #2. The noise between the array sites for this particular sample appears highly incoherent, generally remaining below 0.50 at the lower frequencies. This result suggests that a simple array summation should suppress the noise by a factor of $N^{1/2}$. A computer program, LOPSAN, is available at SDL that measures the RMS noise level (and signal levels as well) of array data before and after summing, or beamforming. Root-mean-square noise measurements from data recorded on 12 February 1967 at 0730Z, 0750Z, and 0810Z were made to determine the amount of noise improvement possible with a zero-delay summation. This recording date was selected on the basis of high apparent noise background. Two combinations of array elements were used in the summations. The following table gives these results.

Time Sample	Elements	Avg. RMS*	Summation RMS	Improvement db	Improvement $N^{1/2}$db
0730-0750	TFO, PY1, 2, 3, 4, 5	47.66	21.01	7.1	7.8
0730-0750	TFO, PY1, 2, 4, 5	46.98	22.02	6.6	7.0
0750-0810	TFO, PY1, 2, 3, 4, 5	47.82	18.84	8.1	7.8
0750-0810	TFO, PY1, 2, 4, 5	47.01	21.89	6.6	7.0
0810-0830	TFO, PY1, 2, 3, 4, 5	58.93	25.13	7.4	7.8
0810-0830	TFO, PY1, 2, 4, 5	57.97	26.24	6.9	7.0

*Each data trace was "demagnified" by an arbitrary value to yield about the same individual RMS level.

The data recorded at PY3 appeared to be questionable so array summations were made both with and without PY3 data. The improvement results in either case are close to the predicted $N^{1/2}$db indicating that the noise is spatially uncorrelated for zero-delay summations.

Multiple Coherences

Multiple coherences as a function of frequency were computed for Noise Samples #1 and #3. Multiple coherence indicates the number of input data channels which would be necessary to describe a noise field and gives a quantitative measure, versus frequency, of how well a linear combination of these n input channels

can match the (n + 1)st channel. The selected output channel for both noise samples was TFO and the inputs were PY1 through PY5. These results indicate that noise sample #3 is multiply incoherent (less than about 0.6) at all frequencies between 0.02 cps and 0.09 cps. The low multiple coherence for sample #3 shows that there are no (or few) linear filter relations between the six elements in the array.

Recorded Signals

Figure 21 shows a strong Love wave recorded by the horizontal instruments at the six sites in the array. Visually, each site appears to record very closely the same signal data on all instruments.

A large teleseismic event was recorded on 13 February 1967 at about 2300Z. Program LOPSAN was used to determine the P-wave S/N improvement from beamforming. Time delays were determined by eye. The results are given below.

Element	S/N
PY1	10.70
PY2	19.90
PY4	19.21
PY5	26.79
TFO	20.50
Mean	19.42
Phased sum	42.72
db improvement	6.8
$N^{\frac{1}{2}}$ db	6.6

Conclusions

1. Ordinary coherence within the passband is high (greater than 0.8) between elements 5-10 km apart, low (less than about 0.6) between elements further apart. Noise Sample #2, however, has low coherence between all sites at all frequencies.

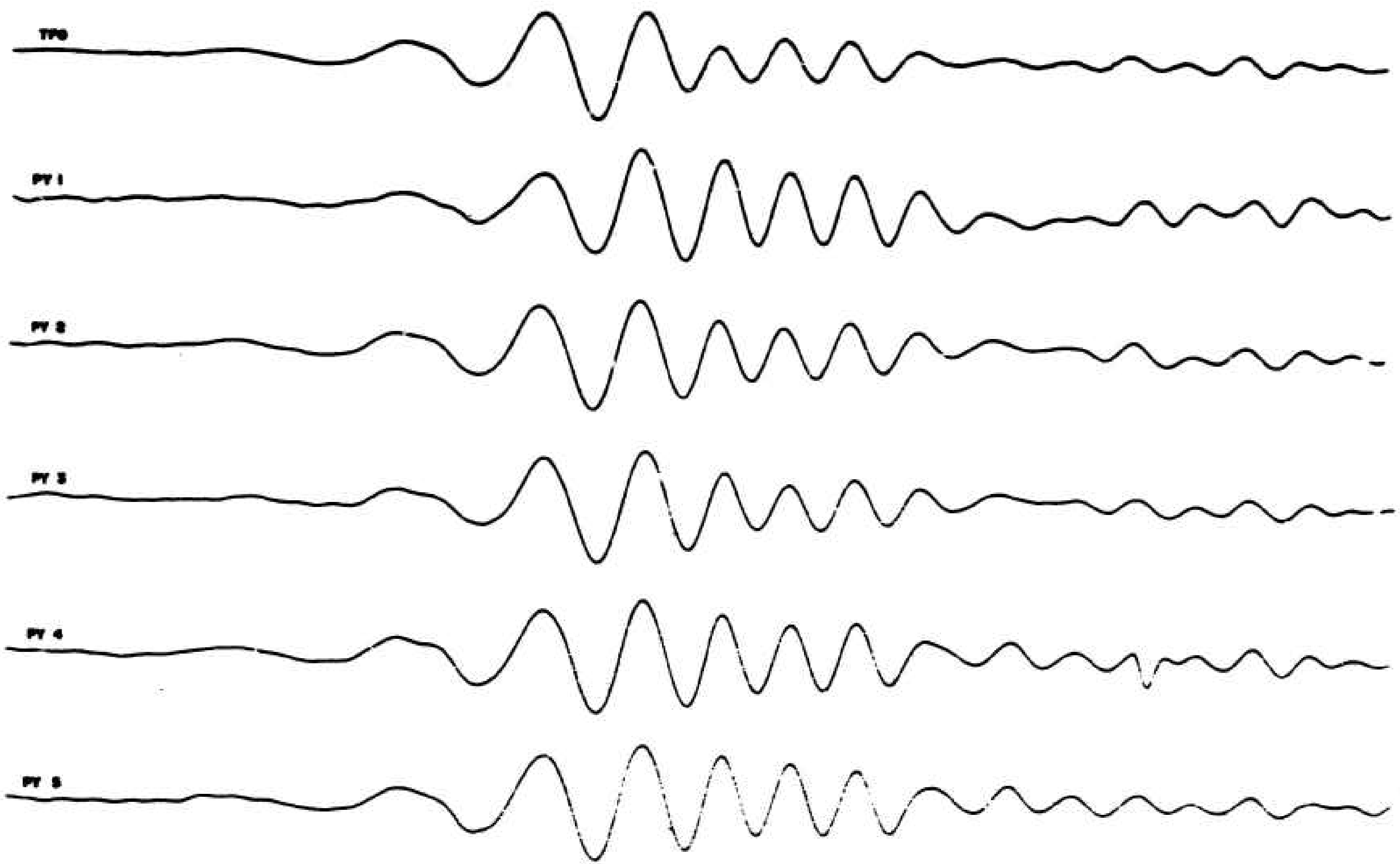

FIGURE 21. LARGE LOVE-WAVE SIGNALS RECORDED AT THE TFSO L-ARRAY.

2. The sites PY5 and PY4 are generally incoherent with the other sites, probably due to local noise characteristics.

3. Multiple coherence is high (greater than 0.7) between 0.02 cps and 0.09 cps for Noise Sample #1 but low (less than 0.6) at all frequencies for Noise Sample #3.

4. Zero-delay RMS noise summations produce about $N^{\frac{1}{2}}$ improvement over the average RMS noise level.

5. Beamforming produces about $N^{\frac{1}{2}}$ improvement in signal-to-noise ratio.

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Chiburis, E.F. and W.C. Dean, 1967a,"Multiple Coherence of Long Period Noise at LASA", Report No. 189, Seismic Data Laboratory, Teledyne, Inc., Alexandria, Virginia.

Chiburis, E.F., and W.C. Dean, 1967b, "Multiple Coherence of Short Period Noise at LASA", Report No. 190, Seismic Data Laboratory, Teledyne, Inc., Alexandria, Virginia.

Chiburis, E.F. and W.C. Dean, 1967c, "Multiple Coherence at 3 Vertical Arrays, UBSO, GV-TX, AP-OK", Report No. 191, Seismic Data Laboratory, Teledyne, Inc., Alexandria, Virginia.

Chiburis, E.F. and W.C. Dean, 1967d, "Multiple Coherence of Short Period Noise at UBSO and TFSO", Report No. 192, Seismic Data Laboratory, Teledyne, Inc., Alexandria, Virginia.

Chiburis, E.F., 1967, "TFSO Long-Period L-Array Noise Coherence, Report No. 199, Seismic Data Laboratory, Teledyne, Inc., Alexandria, Virginia.

III. SUPPORT AND SERVICE TASKS

A. VELA-Uniform Data Services

As part of the contract work statement, the SDL provided one or more of the following support and services functions for VSC and other VELA participants:

- copies of 16 and 35 mm film.
- playouts of earthquakes and special events.
- copies of composite analog tapes.
- composite analog tapes of special events.
- use of 1604 computer for checking out new programs or running production programs.
- copies of digital programs.
- digitized data in standard formats or special formats for use on computers other than the 1604.
- running SDL production programs, such as power spectral density and array processing on specified data.
- digital x-y plots of power spectra or digitized data.
- signal reproduction booklets.
- space for visiting scientists utilizing SDL facilities to study data and exchange information with SDL personnel.

During this report period, 50 such projects were completed and the 18 organizations receiving these services are listed in Appendix A.

B. Data Library

The data library contains approximately 7000 digitized seismograms, 207 digital computer programs and 284 composite analog magnetic tapes, all available for use by the VELA-Uniform program.

The following additions were made during this period:

1. Digital Seismograms - 408 including
   - data from 8 explosions
   - eleven earthquakes recorded at various stations

2. LASA Data - 70 digital tapes

- there are a total of 1276 digital tapes in the library including 983 field tapes. There is also a master calibration tape which contains the magnification (digital counts per millimicron) of each sensor for every subarray. These magnifications have been computed for all calibration tapes currently in house. As each new calibration is received, it is routinely run through the new program CALIBR and added to the master tape.

3. Digital Programs - 21 including:

TFXARY2 - Converts Astrodata multiplex tapes to SDL library format.

MERGSEIS - Reads two seismograms from one tape, rewrites them with 50 channel identifiers.

TFOSAN - Does beamforming and other housekeeping functions.

TFOCAL - Computes magnification levels in counts per micron.

HEFLUMP3 - Designs k space whitening filter.

HEFLUMP4 - Plots high resolution f-k spectra

RCOORD - Computes the projection of seismometer positions along any desired azimuth for k-line spectra.

TSTFFIL - Computes a filtered surface channel, a Brennan sum, a fan filter output, and deghosted downhole channels using the Brennan sum.

LOPAZ63D - Performs low pass and high pass filtering of data on a subset format tape, and produces another subset tape and a plot tape of the filtering data.

CONFIL - Reads band-pass filter coefficients from cards and convolves them with the impulse response of a multichannel filter read from tape. It is designed to process two kinds of multichannel filters, the measured-noise and isotropic processors, from their save tapes.

LSTCHNCE - This program computes and displays the f-k, white noise, and amplitude response functions for theoretical and measured noise and also maximum likelihood filters. The program plots contours of the f-k transfer function, and plots the white noise and amplitude transfer function.

COSPEC - Computes and plots the amplitude, phase and power spectra of a time series sampled at arbitrary times.

RAYTRACE - A ray tracing program using a technique which approximates a velocity-depth profile with a segmented curve having continuous first derivatives.

CANOLCOH - Computes canonical coherence functions using the Cooley-Tukey method for spectral estimates.

NMI1A - To integrate a system of first order differential equations using the Runge-Kutta-Gill method.

SPECSUB2 - To detrend filter (four pole Butterworth), and subset data from either a library or subset tape and plot this data.

LOCATECQ - Performs the same task as the program LOCATE except in the computation of the confidence ellipse. The program uses the chi-square statistic (two degrees of freedom) for confidence ellipse computation, whereas LOCATE uses the f-statistic.

LANDM3 - Given the coefficients of a numerical filter and an input data series, this routine generates the corresponding filtered series. This is basically the same routine as LANDM1 except LANDM1 allows successive calls for filtering consecutive segments of input data, and LANDM3 does not.

LSQSHIFT - This program computes least-squares estimates of the N-1 time shifts between N data channels from the N (N-1) possible cross-correlation functions.

LAMPLOT - To compute and display a response function for the corresponding array. This program is intended as a replacement for program RESPONSE.

NETWORK3 - Designed to replace NETWORK2 and NETWORK4 by providing for numerous computations over and above those described in the writeup of NETWORK2. Among those are the options to process a DEPTHMAG output tape and to determine network detection capabilities.

4. Analog Composite Tapes - 5 including:

a. Made by SDL

- NASH
- BOURBON
- CHARTREUSE

b. Made by Geotech

- KNICKERBOCKER
- ZAZA

C. Data Compression

This is a continuing routine operation, and production is maintained at the level needed to meet the requirements of the field operation (LRSM and U.S. Observatories) and the

Seismic Data Laboratory. For this period 2,715 tapes were compressed.

D. Automated Bulletin Process

July, August, and September 1967 LRSM and Observatory bulletins were processed during this report period and forwarded to Geotech, A Teledyne Company, for checking and publication.

APPENDIX A

October - December 1967

Organizations Receiving SDL Data Services

Vitro
Geotech
University of Cambridge, England
Southwest Center for Advanced Studies
University of California
Texas Instruments
General Atronics Corp.
California Institute of Technology
Pennsylvania State University
Lawrence Radiation Laboratories
University of Michigan
IBM
Lincoln Laboratory
U.S. Coast & Geodetic Survey
Blue Mountain Observatory
Bureau of Public Roads, Phoenix
MIT
Observatorio San Calixto

Unclassified
Security Classification

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3. REPORT TITLE

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4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Quarterly Summary - October - December 1967

5. AUTHOR(S) (Last name, first name, initial)

Dean, William C.

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10. AVAILABILITY/LIMITATION NOTICES

This document is subject to special export controls and each transmittal to foreign governments or foreign national may be made only with prior approval of Chief, AFTAC.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY ADVANCED RESEARCH PROJECTS AGENCY NUCLEAR TEST DETECTION OFFICE WASHINGTON, D. C.

13. ABSTRACT

~~This~~ report discusses the work performed by SDL for the period October through December 1967, and is primarily concerned with seismic research activities leading to the detection and identification of nuclear explosions as distinguished from earthquake phenomenon. Also discussed are the data services performed for other participants in the VELA-UNIFORM project.

14. KEY WORDS

Seismic Data Laboratory - Quarterly

Technical Summary

VELA-UNIFORM Project

Unclassified
Security Classification